Evaluation of ATM 300 Permanent Durable Tape
Montgomery, Vermont
Final Report

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16. Abstract

At the request of a local paving marking industry, a portion of the specified thermoplastic markings were substituted with ATM 300 Permanent Durable Tape on a portion of the Montgomery-Berkshire repaving project, STP 2125(1) S, located on VT 118 between mile marker (MM) 5.565 in Montgomery and MM 1.565 in Berkshire.

The permanent tape was found to be more resistant to wear as compared to thermoplastic markings on this project. However the presence of pits and shadows within and along the thermoplastic markings indicate that they were not installed properly. Therefore, service life was likely compromised and conclusive findings comparing long term durability and retroreflectivity cannot be drawn at this time. Additionally, installation was fairly labor intensive as tape markings must be rolled into the hot mix asphalt during construction. Given the sharp decline and relatively short service life of the permanent tape markings with respect to retroreflectivity and placement methods, the use of these products is only recommended for smaller scale projects with adequate lighting during evening hours, such as signalized intersection.

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1. INTRODUCTION

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. However, traffic markings are often subject to abrasion from tire treads and winter maintenance practices as well as ultraviolet sunlight and fading pigments following application. These factors result in altered color, loss of binder, and loss of reflective elements over time. Durable markings are often applied to newly constructed pavements in the state of Vermont. Markings aretypically re-striped with waterborne paint when warranted. According to the "2006 Standard Specifications for Construction," "durable pavement markings are classified as pavement marking tape, epoxy paint, thermoplastic markings, polyurea paint, and methyl-methacrylate." Each of the referenced markings, comprised of various elements, has been shown to display unique characteristics and varying life cycles.

Durable tapes vary greatly from other liquid applied markings as they are manufactured under controlled conditions whereas markings such as thermoplastic and polyurea are applied in a liquid form to the road surface. Glass beads, which allow drivers to see pavement markings at night, are also incorporated into the material during the tape manufacturing process versus a drop on application for liquid markings. Finally, in accordance with our specifications, pavement marking tapes, when used as durable markings, are to be inlaid into the pavement during compaction of the hot mix asphalt or HMA as opposed to liquid markings which are surface applied following roadway construction.

A recent statewide investigation of various pavement markings found a positive correlation between winter maintenance practices and marking decay due to shearing effects produced by plow operations. If properly inlaid, durable tapes theoretically should be less vulnerable to winter maintenance practices as the surface of the marking should be level to the surface of the pavement. Yet another consideration is that durable tapes have a higher average initial cost making them a less viable alternative to other markings, such as thermoplastic.

Typically, the Agency specifies thermoplastic markings for long line applications along our Vermont and US Routes. At the request of the pavement marking industry for a formal assessment, thermoplastic markings were substituted with permanent tape for a long line rural application along VT Route 118 in the town of Montgomery. The following report summarizes field performance over time in terms of durability and retroreflectivity in comparison to a thermoplastic.

2. PROJECT DETAILS

In association with a federally approved work plan, WP 2007-5 [1], ATM 300 Permanent Durable Tape was applied to a portion of the Montgomery-Berkshire repaving project, STP 2125(1) S, located along VT Route 118 between mile marker (MM) 5.565 in

Montgomery and MM 1.565 in Berkshire. In accordance with the plans, this project included cold planing, reclaiming sections, and resurfacing of the existing highway with a combination of leveling and wearing courses, new pavement markings, guardrail installation, drainage improvements, and incidental items. As specified under the original contract plan, thermoplastic pavement markings were to be applied throughout the limits of the project. However, a representative of the pavement marking industry expressed interest in the assessment of permanent tape in a long line application emphasizing benefits of physical properties and reported long term durability. Once agreed upon by the resident engineer, project manager, and Federal Highway Administration, the contract was modified for the application of permanent tape. Advanced Traffic Markings offered to supply the state with 9,000 linear feet (LF) of white and yellow durable marking tape. Approximately 4,682 LF of white edge line was applied between MM 7.79 and MM 8.23 and 5,164 LF of yellow centerline was applied between MM 7.74 to MM 8.23 at the discretion of the resident engineer in the town of Montgomery. The average annual daily traffic (AADT) specific to this area is 2,200. Thermoplastic paint markings were applied to the remainder of the project as shown within the quantity sheets of the project plans.

3. PRODUCT DETAILS

According to the manufacturer, Advanced Traffic Markings, Inc. from Roanoke Rapids, NC, ATM 300 Permanent Durable Tape is lead free and environmentally safe. Reportedly, it meets or exceeds ASTM D4505, “Standard Specification for Preformed Retroreflective Pavement Marking Tape for Extended Service Life” [2] and is marketed as a tape consisting of high quality polymeric materials, pigments, and glass beads to assure long term retroreflectivity. It has a pre-applied, pressure sensitive adhesive that minimizes tape movement in hot and cold climates. The ATM adhesive system is claimed to extend the application season as well. When applied in accordance with the manufacturer’s recommendations it reportedly adheres to asphalt or Portland cement concrete roadway surfaces and should provide a minimum service period of 16 months in a light to moderate traffic volume.

ATM 300 Permanent Durable Tape is the manufacturer’s “moderate grade” permanent tape. The tape is recommended for use in both longitudinal and transverse applications. It is a minimum of 60 mil (1.52 mm) thick to resist wear. Supposedly, the tape offers optional anti-skid particles and reportedly has an initial minimum skid resistance of 45 British Pendulum Number (BPN) when tested according to ASTM E 303-83, “Test Method for Measuring Surface Frictional Properties Using the Bridge Pendulum Tester” [3]. The inlay method requires pavement temperatures of 120°F to 175°F. All specifications and application instructions are provided in Appendix A.

4. INSTALLATION AND OBSERVATIONS

Application of the ATM 300 permanent tape was completed on Monday and Tuesday, September 17th and 18th, 2007. According to the construction notes, the ambient air temperature ranged from 32°F to 67°F on September 17th, and from 38°F to 69°F on September 18th. Conditions on both days were sunny with no reported precipitation. The average humidity was roughly 80% on both days. Pike Industries, Inc. was the prime contractor for this project, responsible for paving activities, while Scott's Line Striping was the subcontractor for the application of traffic markings.

Scott's Line striping monitored the temperature of the hot mix asphalt (HMA) following initial compaction to determine the appropriate time for the placement of the permanent marking tape. With respect to the longitudinal markings, once the pavement cooled to acceptable temperatures, the striping company offset the placement of the centerline marking so that the marking material would not be applied directly over the joint. After the centerline was established, both white edge lines were marked in accordance with the plans. A handcart was used to apply the marking tape. The handcart was equipped with a special cutting blade providing an even finish. The third and final roller for compaction of the HMA inlaid the tape into place. Pavement temperatures were also monitored by staff from the Materials and Research Section during application of the ATM permanent tape. All readings were found to be within the manufacturer's recommendation. A summary of the application dates in association with ambient temperature conditions [4] are provided below in Table 1. According to the specifications from ATM, "ambient temperatures, 24 hours before and after (application), of 40°F or rising (is required)." In examining reported ambient air temperatures provided below, this requirement was not met during evening hours.

Beginning Station	Ending Station	Application Location	Marking Type Applied	Date of Application	Ambient Temperatures(1)
411+25	434+66	Northbound Lane	ATM 300 White Edge	09/17/2007	32°F to 67°F
411+25	434+66	Southbound Lane	ATM 300 White Edge	09/18/2007	38°F to 69°F
408+93	434+78	Centerline	ATM 300 Yellow Center	09/18/2007	38°F to 69°F
488+77	82+24	Centerline	Thermoplastic Yellow Center	09/25/2007	55°F to 83°F
290+90	488+77	Centerline	Thermoplastic Yellow Center	10/01/2007	44°F to 67°F
291+60	82+28	Southbound Lane	Thermoplastic White Edge	10/04/2007	60°F to 80°F
291+60	380+35	Northbound Lane	Thermoplastic White Edge	10/04/2007	60°F to 80°F
380+35	411+25	Northbound Lane	Thermoplastic White Edge	10/05/2007	50°F to 84°F
434+68	82+28	Northbound Lane	Thermoplastic White Edge	10/05/2007	50°F to 84°F

(1) Reported ambient air temperature range 24 hours prior to and following application

Table 1. Pavement marking installation data

It is important to emphasize the construction sequence requirements associated with inlaying permanent marking tapes. Typically tapes are inlaid following initial compaction and prior to final compaction of the HMA within a specified temperature range. Additionally, tapes are generally applied using hand carts as opposed to truck applicators for liquid markings. These methods require significant coordination between the paving operator and marking applicator and typically lengthen time for HMA construction.

General observations during application included the ease of tape removal. As depicted in Figure 1, the tape readily lifted with minimal hand force while the pavement was still warm. However, the tape appeared to be well adhered to some portions of the pavement. This may indicate that the pavement was not thoroughly cured. There was also some evidence of shrinkage at the beginning and ending of each continuous tape section. The shrinkage appeared to pull the surface of the HMA as well. Interestingly, application literature states, “if tape distorts or wrinkles, surface temperature may be too hot or roller speed may be too fast.” These areas were monitored periodically during the study duration.

Figure 1. Tape lifted

Thermoplastic markings, or the control markings for this study, were applied during the first week of October. Unfortunately, Research personnel were not onsite to monitor the application process. However, the appearance of gas bubbles within the thermoplastic markings, as well as shadows was noted during a site visit performed on October 10th as displayed in Figures 2 and 3. According to literature provided by Ennis Paint, gas bubbles are generally caused by either moisture or solvent trapped in the hoses or from overheating. Thermoplastic shadows may be generated by a heavily undulated road surface or die not riding evenly on the substrate. In either case, evidence suggests some problems during application, which may have ultimately affected long-term durability and retroreflectivity.

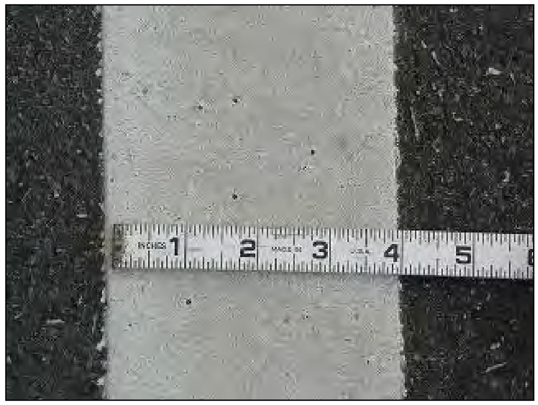


Figure 2. Gas bubbles in line (test site 1)

Figure 3. Material shadows on line (test site 2)

5. SURVEILLANCE AND TESTING

A total of six test sites were established throughout the length of the project in order to collect retroreflectivity readings in accordance with ASTM E 1710-97, “Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer” [5], and durability evaluations, in accordance with ASTM D 913-03, “Evaluating Degree of Resistance to Wear of Traffic Paint” [6]. Two test sites, denoted as TS 1 and TS 2, were established along the thermoplastic traffic markings as well as four sites, identified as TS 3 through TS 6, along the experimental permanent tape. Each test site was established in an area with good sight distance on a straight away and consisted of a total length of 40 feet with data collection conducted at 10 foot intervals starting from the beginning of the test site. Surveillance was performed along both white edge lines and yellow centerlines. Each data collection location was identified with white marking paint along the shoulder of the driving lane in order to ensure that all future readings would be collected from the same location.

Retroreflectivity readings and visual assessments were collected utilizing a LTL 2000 retroreflectometer which employs 30 meter geometry. Photographic documentation was also gathered at individual test site locations during each field visit. All retroreflectivity and durability readings were recorded onto the appropriate field forms and then compiled into a dedicated spreadsheet.

5.1 Initial Performance

Initial site visits pertaining to the experimental markings were conducted on September 18th and September 25th, on the day of and 7 days following application, respectively. An initial assessment of the thermoplastic markings was conducted on October 10th, 5 days following the application of the white edge line thermoplastic markings and 9 days following the application of the yellow centerline traffic markings.

A summary of initial retroreflectivity readings is provided within Table 2 below. Please note that most of the experimental markings and all of the thermoplastic markings were found to be in compliance with ASTM 6359, "Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments" [7] which requires a minimum retroreflectivity of 250 mcd/m^2/lx for white marking and 175 mcd/m^2/lx for yellow markings within 14 days of application. Any readings below the referenced ASTM standard are shown in blue font.

Initial Average Retroreflectivity Summary							
		Permanent Tape Markings				Thermoplastic	
		White Edge Lines		Yellow Center Lines		White	Yellow
Test Site ID:	Date:	9/18/2007	9/25/2007	9/18/2007	9/25/2007	10/10/2007	10/10/2007
	Days Since Application:	0	7	0	7	5	9
TS 1	SB	-----	-----	-----	-----	370	192
	NB	-----	-----	-----	-----	403	197
TS 2	SB	-----	-----	-----	-----	401	185
	NB	-----	-----	-----	-----	413	197
TS 3	SB	612	731	698	772	-----	-----
	NB	**95**	219	698	770	-----	-----
TS 4	SB	975	961	672	617	-----	-----
	NB	**111**	**181**	620	650	-----	-----
TS 5	SB	705	656	767	776	-----	-----
	NB	688	772	709	724	-----	-----
TS 6	SB	822	503	687	524	-----	-----
	NB	677	573	593	649	-----	-----
Average:		**586**	**575**	**681**	**685**	**397**	**193**
Std. Dev:		**318**	**269**	**54**	**91**	**19**	**6**

Table 2. Initial performance comparison

The average initial retroreflectivity of the white and yellow ATM 300 markings was 585 and 681 mcd/m^2/lx, respectively. This is somewhat counterintuitive as yellow markings typically display decreased luminance readings as opposed to their white counterparts due to pigmentation. Excess asphalt binder was observed on top of the permanent tape markings located in the northbound lane of test sites 3 and 4 most likely reducing retroreflectivity values. Readings collected 7 days following application were consistent with those collected immediately following application. Comparatively, the average retroreflectivity of the thermoplastic markings 5 days following the application of the white edge lines and 9 days following the application of the yellow centerlines was 397 and 193 mcd/m^2/lx, respectively. The ATM 300 permanent tape displayed moderate standard deviations indicating some variability while the standard deviations for the thermoplastic traffic markings were very low signifying consistency of the material.

5.2 Long Term Performance

In addition to verifying initial retroreflectivity compliance with ASTM D 6359, all markings were monitored for performance over time. The service lives of pavement markings were used to compare durability and degradation rates to a predefined benchmark in order to evaluate and determine life cycle costs. To date, the Federal Highway Administration, or FHWA, and other federal and state authorities have not established a minimum requirement for retroreflectivity of pavement markings. However, FHWA has compiled recommended retroreflectivity guidelines for white and yellow pavement marking for different classes of roads as shown in Table 3. VT 118 in town of Montgomery is classified as a Non-Freeway road with posted speed limits 40 mph or below. Therefore, the recommended minimum retroreflectivity for white and yellow markings along this roadway segment are of 85 and 55 mcd/m^2/lx, respectively.

1998 FHWA Research-Recommended Pavement Marking Values			
Type	**Non-Frwy**	**Non-Frwy**	**Freeway**
Option 1	<= 40 mph	>= 45 mph	>= 55 mph
Option 2	<= 40 mph	>= 45 mph	>= 60 mph, >10K ADT
Option 3	<= 40 mph	45-55 mph	>= 60 mph
White	85	100	150
Yellow	55	65	100

Table 3. FHWA recommendations

5.2.1. White Edge Lines

Table 4 as shown below, contains a summary of average reflectance for the white experimental and control pavement markings. Any readings below 85 mcd/m^2/lx are highlighted in red font.

Long Term Retroreflectivity Performance of White Edge Lines								
Collection Date:		10/10/2007	11/14/2007	4/15/2008	7/10/2008	9/25/2008	5/21/2009	7/27/2009
Thermoplastic Markings								
Days Since Application:		-----	40	193	279	356	594	661
TS 1	SB	-----	387	113	175	182	118	125
	NB	-----	443	185	186	151	141	104
TS 2	SB	-----	359	111	173	175	97	103
	NB	-----	473	173	182	164	149	141
Average:		-----	416	146	179	168	126	118
Permanent Tape Markings								
Days Since Application:		22	57	210	296	373	611	678
TS 3	SB	568	490	83	73	73	35	35
	NB	454	284	35	26	23	27	26
TS 4	SB	677	618	153	227	174	62	52
	NB	522	507	97	93	67	42	39
TS 5	SB	700	553	39	35	32	30	34
	NB	698	502	31	29	24	33	43
TS 6	SB	646	695	105	93	49	37	37
	NB	578	497	95	88	54	35	37
Average:		605	518	80	83	62	38	38

Table 4. Long term performance comparison of white edge lines

Initially, the ATM 300 traffic markings displayed a greater luminance as compared to the standard thermoplastic markings and exhibited fairly consistent retroreflectivity readings prior to the first winter season with the exception of the northbound lane within TS 3 and 4. These values are likely lower due to the observed asphalt binder covering portions of the markings. Retroreflectivity values of both the experimental and control markings were found to decay readily during the first winter season most likely due winter maintenance practices and sheering effects from plow blades. However, after the winter season, the thermoplastic markings appear to outperform the experimental markings and had yet to fall below minimum recommended values as of July 27, 2009. ATM product representatives, following the first winter season, explained that with continued wear a second layer of glass beads would be exposed, thus raising the retroreflectivity values somewhat. Following two years of service this has not been observed, as retroreflectivity values continued to decrease throughout the monitoring period.

5.2.2. Yellow Centerlines

A similar analysis was performed with the yellow pavement markings with a minimum FHWA acceptable retroreflectivity of 55 mcd/m^2/lux as displayed in Table 5. Please note that any readings below 55 mcd/m^2/lux are highlighted in red.

Long Term Retroreflectivity Performance of Yellow Centerlines								
Collection Date:		10/10/2007	11/14/2007	4/15/2008	7/10/2008	9/25/2008	5/21/2009	7/27/2009
Thermoplastic Markings								
Days Since Application:		-----	40	193	279	356	594	661
TS 1	SB	-----	69	95	104	60	82	84
	NB	-----	84	99	100	69	84	91
TS 2	SB	-----	86	95	84	51	58	56
	NB	-----	85	88	76	61	54	39
Average:		-----	81	94	91	60	70	68
Permanent Tape Markings								
Days Since Application:		22	57	210	296	373	611	678
TS 3	SB	590	29	20	17	25	22	27
	NB	541	33	26	21	28	22	24
TS 4	SB	537	29	24	19	32	23	32
	NB	613	27	21	16	32	21	25
TS 5	SB	735	24	23	26	25	27	37
	NB	632	25	22	22	25	26	30
TS 6	SB	610	35	30	24	28	25	29
	NB	573	38	29	54	26	25	29
Average:		604	30	24	25	28	24	29

Table 5. Long term performance comparison of yellow centerlines

Once again, the ATM 300 retroreflectivity readings were much greater initially as compared to the standard waterborne markings. Prior to the winter season, the ATM markings displayed fairly consistent retroreflectivity values while the thermoplastic markings exhibited 58% degradation, on average, over a one month period. Following the first winter season, the experimental markings demonstrated a sharp decline in retroreflectivity readings with an average degradation of 95%. Conversely, retroreflectivity readings for the control markings remained roughly the same prior to and following winter seasons and had yet to fall below the FHWA recommended minimum values as of the final site visit.

5.3 Appearance of ATM 300 and Thermoplastic

Another important aspect of pavement marking durability is resistance to wear. Line appearance and its resistance to wear is an important factor, as the pavement marking substrate provides roadway delineation during daylight hours. Over time pavement markings can fade, crack, pit, and debond from the underlying surface. In the case of permanent tapes, a concern expressed by representatives of the Operations Division pertained to damage as a result of winter maintenance practices potentially resulting in a significant loss of the markings. Any damage may reduce driver awareness, regardless of the retroreflectivity values, as the road boundaries begin to disappear. Therefore, marking appearance was examined during each site visit in accordance with ASTM D 913-03. Appearance was expressed with a number between 0 and 10, 0 representing a line that is no longer visible and a 10 representing a line in perfect condition. A summary of line appearance over time is provided in Table 6.

Wear Reading Summary								
Collection Date:		10/10/2007	11/14/2007	4/15/2008	7/10/2008	9/25/2008	5/21/2009	7/27/2009
Thermoplastic Markings								
Days Since Application:		5	40	193	279	356	594	661
TS 1	W	10	3	5	3	2	2	2
	Y	10	7	7	7	5	5	2
TS 2	W	10	3	3	3	2	2	3
	Y	10	8	7	7	3	3	3
Average:		10	5	6	5	3	3	3
Permanent Tape Markings								
Days Since Application:		22	57	210	296	373	611	678
TS 3	W	10	9	7	7	7	7	5
	Y	10	9	7	7	7	7	5
TS 4	W	10	9	7	7	7	7	6
	Y	10	9	7	7	7	7	6
TS 5	W	10	7	7	7	7	7	5
	Y	10	8	7	7	6	6	5
TS 6	W	10	9	7	7	7	7	6
	Y	10	9	7	7	7	7	6
Average:		10	9	7	7	7	7	6

Table 6. ATM 300 and thermoplastic wear readings

As shown above, the thermoplastic marking were less resistant to wear over time as compared to the experimental permanent tape markings. Within 40 days of application, the average wear rates for the control markings decreased by 50% while the wear rates for the ATM markings decreased by only 10% within the same timeframe. Following the winter season, the wear readings for the thermoplastic markings remained constant while the experimental markings decreased slightly. However, after two years of service, the wear readings for the experimental markings are almost twice that of the standard markings. Observations of the thermoplastic markings immediately following application indicated that the markings were likely not applied properly as evidenced by bubbles in the line and overshadowing. This may have resulted in premature wear. In addition, as stated previously, the tape markings were recessed into the pavement most likely shielding the substrate from damage induced by winter maintenance practices and tire treads. Figures 4 through 7 below demonstrate general wear of the ATM and thermoplastic traffic marking after approximately two years of service.

Figure 4. Yellow thermoplastic photo from 7/27/2009

Figure 5. Yellow ATM 300 photo from 7/27/2009

Figure 6. White thermoplastic photo from 7/27/2009

Figure 7. White ATM 300 photo from 7/27/2009

5.4. Service Life

Service life estimates for the white edge line and yellow centerline pavement markings could not be determined due to the large extent of time between data collection events. Therefore, a scatter plot of the data was generated in order to establish the approximate amount of elapsed time before retroreflectivity values fell below 85 and 55 mcd/m^2/lx, respectively, as shown in Figures 8 and 9. The model below assumes a linear rate of decay between data collection events.

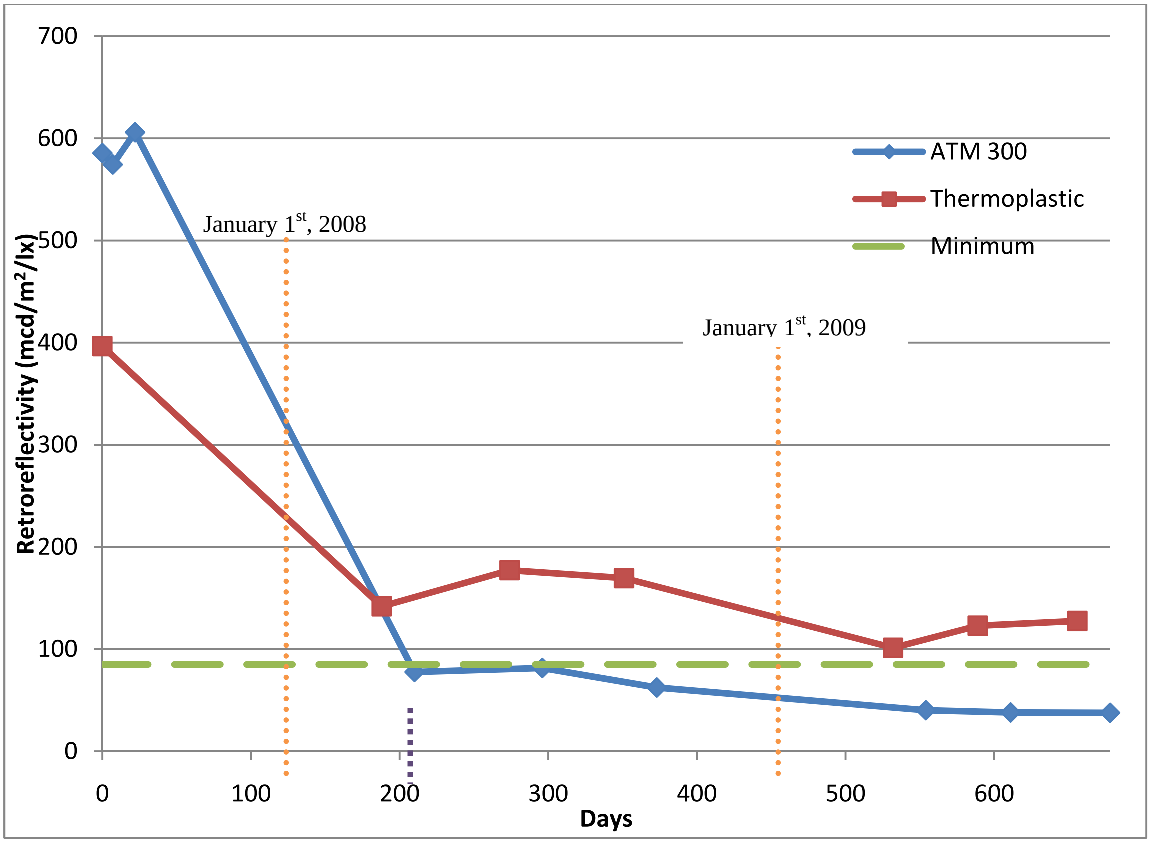


Figure 8. Averaged retro values of the white pavement markings, with FHWA recommended minimum of 85 mcd/m^2/lx displayed. Vertical orange lines indicate a date of January 1st, while purple indicates the day when retroreflectivity values fell below the minimum.

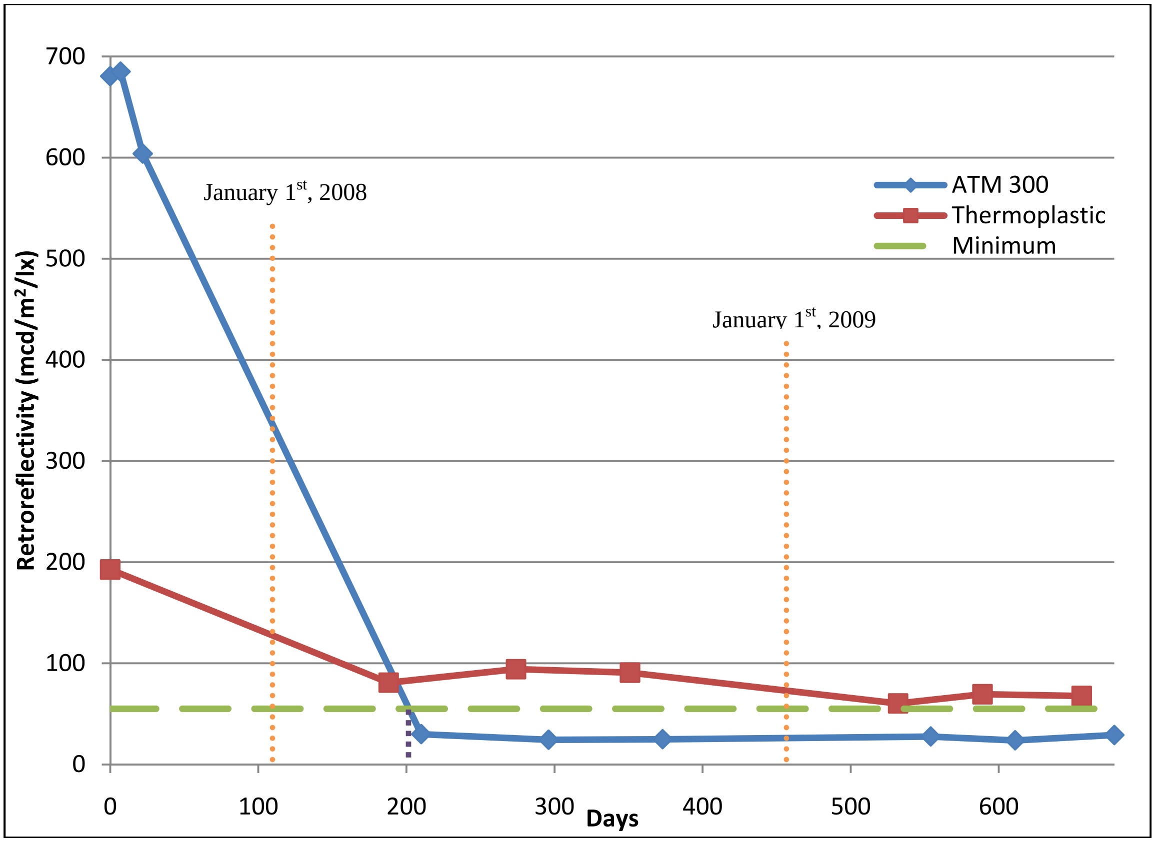


Figure 9. Averaged retro values of the yellow pavement markings, with FHWA recommended minimum of 55 mcd/m^2/lx displayed. Vertical orange lines indicate a date of January 1st, while purple indicates the day when retroreflectivity values fell below the minimum.

The graphical representations clearly display a strong positive correlation between winter maintenance practices and pavement marking decay for both marking materials. The effects of the first winter season appear to result in the greatest decay over the monitoring period whereas the second winter season appears to have minimal impact on pavement marking retroreflectivity. It is likely that the majority of the bead loss occurred during the first winter season and any remaining beads were sufficiently embedded into the permanent marking tape and thermoplastic as to be protected from subsequent plowing events. The average retroreflectivity values for the white and yellow ATM 300 tape were below FHWA recommended minimums roughly 208 and 200 days following construction, respectively. As evidenced in a previous statewide study, thermoplastic markings appear to rebound by increasing in retroreflectivity during the summer and fall months and have yet to fall below FHWA recommended minimums.

5.5. NTPEP Test Deck

ATM 300 markings were assessed through the National Transportation Product Evaluation Program (NTPEP), a program intended to eliminate duplicative testing by member states. The markings were applied to a test deck in Pennsylvania on July 10th,

2008. In addition to the Pennsylvania test deck, the ATM 300 product was placed on a Mississippi test deck in 2006. However given the different climatic conditions, the results are not considered relevant to Vermont.

NTPEP test decks require the application of four beaded transverse lines, spanning the width of a travelled lane, per product [8]. The four transverse lines are applied to two separate areas allowing for a better statistical representation of the product. Transverse lines provide a comparison between lines that are heavily travelled by traffic (in the wheel paths) and areas with little to no traffic (near the centerline). Data from these test decks are recorded monthly, weather permitting. Retroreflectivity is assessed in the left wheel path and in close proximity to the centerline of the road. Readings are also collected with a 30 meter CEN geometry portable retroreflectometer in accordance with ASTM D 1710. Test deck locations are chosen on level, straight roadways, with no intersections and AADTs greater than 5,000. Preliminary results from the Pennsylvania test deck are presented in Table 7.

NTPEP Test Deck Summary - ATM 300 Markings					
Date of Collection	Days Since Installation	White		Yellow	
		Skip	Left Wheel	Skip	Left Wheel
7/28/2008	18	451	646	403	482
8/26/2008	47	480	339	406	291
9/30/2008	82	442	281	376	206
10/27/2008	109	424	241	389	168
4/28/2009	292	149	76	160	32
5/19/2009	313	160	67	158	32
7/9/2009	364	112	58	122	26
7/28/2009	383	128	55	129	27
10/26/2009	473	112	53	118	25
4/19/2010	648	92	48	82	25

Table 7. ATM 300 retroreflectivity readings from 2008 Pennsylvania NTPEP test deck on asphalt.

Just as within this project, the NTPEP data shows a sharp decrease in values following the winter plowing season, in some cases well below the FHWA recommended minimums, especially for the well travelled left wheel paths validating our results.

5.6.Cost Analysis

Advanced Traffic Markings furnished roughly 9,846 linear feet of ATM 300 permanent marking tape at no additional cost to the state. Specifically, the installation included 2,341 linear feet of 4" white edge line traffic markings and 2,582 linear feet of yellow centerline markings along both lanes within one roadway segment.

5.6.1 Life Cycle Cost Analysis

For analysis purposes, ATM representatives provided a cost estimate of $2.00/ft^2 for the ATM 300 Tape. This is equivalent to $0.66/LF for a 4" wide line. Comparatively, thermoplastic paint typically costs $0.48/LF for a 4" wide line. Accurate installation costs for these products are not known, however approximate values based on historical data indicates that inlaid ATM 300 costs $3.00 a linear foot to apply while thermoplastic costs $0.55. This brings total material plus installation costs to $1.03 for thermoplastic and $3.66 for ATM 300. Table 8 provides a cost comparison between the experimental and control pavement markings. Service life is based on time elapsed between placement and when retroreflectivity readings were estimated to have fallen below FHWA recommended minimums.

ATM 300 Cost Comparison Per LF ($/4" wide line)					
Material	Material Cost	Installation Cost	Total Cost	Service Life	Cost/Month
ATM 300	$0.66	$3.00	$3.66	6.7	$0.55
Thermoplastic	$0.48	$0.55	$1.03	N/A	N/A

Table 8. Pavement marking life cycle cost comparison

It is interesting to note that in this case, costs for the marking substrates are similar. However, installation costs vary greatly further supporting the notion that permanent pavement markings tapes may not be appropriate for long line applications.

5.6.2 Net Benefit Cost Analysis

Another methodology to compare the cost effectiveness of a marking material is to determine its net benefit to users over its lifespan with consideration to increased retroreflectivity and older drivers. A study conducted by the University of North Carolina at Charlotte concluded "that nighttime luminance levels provided by pavement markings that may be adequate for younger drivers may be less than adequate for older drivers" [9]. Therefore, rather than examining the amount of time until retroreflectivity levels fall below a minimum recommended level, the following assessment accounts for the retroreflectivity readings over time above minimum recommended levels as a net benefit. The net benefit is calculated by a summation of the area between the averaged retroreflectivity readings and FHWA recommended minimum in Figures 8 and 9, until readings fall below the minimum value. While the thermoplastic markings have yet to fall below the minimum criteria, the additional value of the area is considered minimal. Therefore, any additional benefit following the last data collection event is not considered in the analysis presented below.

Based upon the service lives of the markings derived from recorded retroreflectivity values, the net benefits of the materials and the benefit per total cost per foot are summarized in Table 9.

ATM 300 Net Benefit Analysis			
Material	**Color**	**Benefit ($mcd/lx/m^2$*days)**	**Benefit Per Cost/Foot**
Thermoplastic	White	61,263	59,479
	Yellow	26,271	25,506
ATM 300	White	59,491	16,254
	Yellow	62,089	16,964

Table 9. Net benefit to user values.

As shown in the table above, white thermoplastic markings provided a greater benefit, 3% on average, in comparison to the white permanent tape markings. This is equivalent to a 266% increase in the benefit cost per foot for the white thermoplastic markings. Conversely, the yellow ATM markings exhibit a larger benefit over the yellow thermoplastic markings, an average of 136%, however due to the cost associated with the tape, the benefit per cost foot of the thermoplastic is more advantageous at a value of 50% greater.

It is important to note that the total benefit for a marking in Vermont is directly related to how early in the marking season a line is placed. If it is placed at the beginning of the construction season the public has the remainder of the summer and fall to benefit from superior performance. Conversely when applied at the end of the construction season, markings decay quickly with the onset of winter maintenance activities making the marking far less beneficial with respect to safety and life cycle cost. Therefore, the benefit analysis can only be used as a qualitative comparison between two materials that have been placed on near identical dates.

6. SUMMARY AND RECOMMENDATIONS

An experimental permanent pavement marking tape known as ATM 300 was applied to the Montgomery-Berkshire resurfacing project, STP 2125(1) S, located along VT 118 between MM 7.74 and MM 8.23 in the town of Montgomery to compare its long term performance to thermoplastic, a commonly specified traffic marking for long line applications. Overall, the process was found to be more labor intensive as compared to the installation of liquid pavement markings, such as thermoplastic and polyurea. Per the Agency' specification for final durable marking, the tape was inlaid into the pavement by the final roller during the placement of the hot mix asphalt requiring extensive coordination between paving contractor and pavement marking applicators. Thermoplastic markings, the control marking for this study, were applied to the remainder of the project. The appearance of gas bubbles within the thermoplastic markings as well as shadows were noted during an initial site visit indicating problems during application; this most likely compromised long term.

Six test sites were established throughout the length of the project for the collection of retroreflectivity and wear readings, two for the control and four for the experimental markings. All of the experimental tape and thermoplastic markings were found to be well above the ASTM specified minimum required retroreflectivities for newly applied markings with the exception of the northbound lane of test sites 3 and 4 containing ATM 300 tape. However, asphalt binder was noted on the top of these lines likely accounting for lower retroreflectivity values. Following a two year monitoring period, service life estimates were derived by calculating the amount of time elapsed between marking application and when the markings fell below FHWA minimum recommended retroreflectivity levels. The ATM 300 white markings fell below this threshold at approximately 208 days while the yellow markings fell below acceptable levels roughly 200 days following application. The steep decay in retroreflectivity values is likely due to winter maintenance activities. Conversely, the thermoplastic markings had yet to fall below the FHWA minimums following two years of service life. Appearance ratings, while subjective, show that the ATM 300 tape is more resistant to wear over time. This result may have been influenced by poor application of the thermoplastic traffic markings.

A cost comparison shows that the ATM 300 tape in terms of material and installation is 255% more expensive than thermoplastic, $3.66 versus $1.03 a linear foot for a 4 inch line. Unfortunately, a cost per month based derived from service life estimates could not be performed as the average control marking retroreflectivity had yet to fall below the FHWA recommended minimums. Another methodology to compare the cost effectiveness of a marking material is to determine its net benefit to the user over its lifespan with consideration to increased retroreflectivity and older drivers. Therefore, rather than examining the amount of time until retroreflectivity levels fall below a minimum recommended level, this analysis accounted for the retroreflectivity readings over time above minimum recommended levels as a net benefit. Results indicate that the net benefit for the thermoplastic product exceeded that of the ATM 300 for both white and yellow markings on a per cost basis.

Given the constructability requirements and long term performance, long line application of ATM 300 permanent tape is not recommended at this time. With consideration to the sharp decay of the retroreflectivity readings following the winter season but relatively good resistant to wear during the monitoring period, the placement of ATM 300 markings would be appropriate for smaller construction projects with adequate ambient lighting during evening hours, such as signalized intersections.

REFERENCES

[1] Fitch, Jennifer and Peterson, Christopher. *Work Plan for Research Investigation: ATM 300 Permanent Durable Tape, Work Plan No. WP-2007-5*. Vermont Agency of Transportation, 2007.

[2] ASTM D 4505, "Standard Specification for Preformed Retroreflective Pavement Marking Tape for Extended Service Life," ASTM International, West Conshohocken, PA, <www.astm.org>.

[3] ASTM E 303-83, "Test Method for Measuring Surface Frictional Properties Using the Bridge Pendulum Tester," ASTM International, West Conshohocken, PA, <www.astm.org>.

[4] www.weatherunderground.com from Weather Underground Inc.

[5] ASTM E 1710-97, "Standard Test Method for Measurement of Retroreflective Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer," ASTM International, West Conshohocken, PA, <www.astm.org>.

[6] ASTM D 913-03, "Evaluating Degree of Resistance to Wear of Traffic Paint," ASTM International, West Conshohocken, PA, <www.astm.org>.

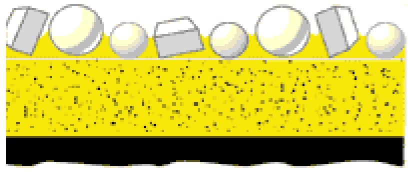
[7] ASTM D 6359-99, "Minimum Retroreflectance of Newly Applied Pavement Marking Using Portable Hand-Operated Instruments," ASTM International, West Conshohocken, PA, <www.astm.org>.

[8] Project Work Plan for the Field and Laboratory Evaluation of Pavement Marking Materials, National Transportation Product Evaluation Program, August 2008.

[9] Graham, Johnny R., Harrold, Joseph K., King, L. Ellis, "Pavement Marking Retroreflectivity Requirements for Older Drivers", Transportation Research Record, Volume 1529, pp. 65-70, 1996.

APPENDIX A

ATM Permanent Series 300 & 400
Preformed Polymer Tape
Specifications[1]



- Meets Or Exceeds ASTM D4505-01a Standard Specification For Preformed Retroreflective Pavement Marking Tape For Extended Service Life

Series 300 Durable preformed plastic, permanent marking tapes are designed for usage on asphaltic or concrete surfaces. Series 300 tapes are suitable for longitudinal markings and transverse markings including word/symbol markings. Series 300 Durable tape is available in white, yellow and custom colors.

Series 400 Extended Life preformed plastic, permanent marking tapes are designed for usage on asphaltic or concrete surfaces. Series 400 tapes are suitable for longitudinal markings and transverse markings including word/symbol markings. Series 400 Extended Life tape is available in white, yellow and custom colors.

PHYSICAL PROPERTIES

Composition: All Permanent Series Tapes consists of a pre-applied, pressure sensitive adhesive with high quality polymeric materials, pigments and glass beads assuring long term retroreflectivity.

Applicability To Pavement Surfaces: Ambient temperatures, 24 hours before and after, of 50°F (10°C) and rising. See Manufacturers Application Instructions included in each box.

Adhesion: Permanent Series Tapes will adhere to asphalt or portland cement concrete roadway surfaces when applied according to the manufacturer's recommended procedures.

Pigmentation: Permanent Series Tape pigments are selected and blended to provide a marking tape in white or yellow conforming to standard highway colors.

Skid Resistance: Permanent Series 300 and 400 tapes will have an initial minimum skid resistance value of 55 BPN when tested according to ASTM E 303.

Reflectance: Permanent Series Tapes have the following minimum results when tested in accordance with ASTM D4061.

	White		**Yellow**	
Entrance Angle-Degrees	86.0	86.0	86.0	86.0
Observation Angle-Degrees	0.2	0.5	0.2	0.5
Specific Luminance (mcd ft^{-2} $(fc)^{-1}$)	1770	1270	1310	1000
LTL 2000 Reflectometer	800		600	

Performance Requirements: Series 300 tape, when applied according to the manufacturer's recommendations, shall provide a minimum service period of 24 months in light to moderate traffic volume.

Series 400 tape, when applied according to the manufacturer's recommendations,shall provide a minimum service period of 36 months in moderate to heavy traffic volume.

In snow removal areas, plowing may shorten tape's life cycle.

Series 300 and 400 are also available with extended four and six year warranties. Please contact your ATM Sales Representative for specifications.

[1] From http://www.trafficmarkings.com/atm_300_tape_specs.html

ATM PERMANENT PREFORMED POLYMER TAPES APPLICATION INSTRUCTIONS[2]

Overlay Method

- Air and surface temperature must be 50°F (10°C) and rising.
- Surface must be completely dry.
- Surface must be clean and free of any contaminants which may include but not limited to oils, grease, sand, dirt, dust, loose aggregate, curing compound, mud, soil and salt.
- Portland Cement concrete curing compound must be completely removed by pressure washing, sandblasting, or grinding the road surface.
- ALWAYS USE BUTT SPLICES.
- Do not apply tape directly over deteriorating markings or substrates, or lane delineation devices.
- Tapes or Rumble Strips applied directly over seams and joints must be cut through 1" on both sides of the joints or seams to prevent de-bonding of large sections of tape.
- Apply an ATM primer on all surfaces except newly laid asphalt, up to one year and in good to excellent condition. Allow adhesive to completely dry before installing the markings.
- Use ATM Permanent Primer on completely cured surfaces if it has rained 6 hours prior to, or it is expected 24 hours after installation.
- Firmly tamp longitudinal tape in the same direction as tape was applied on the initial pass. A minimum of three passes total are required. Use a tamper device with a minimum 200 lb. (90kg) load and a tamping surface a minimum 2" wider than the width of tape being applied. Never twist the tampering device during tamping. Repeat tamping as necessary to insure tape has completely conformed to the road surface.
- Marked roadway can be open to traffic immediately.
- Firmly tamp transverse marking symbol/legends using an approved ATM Tamper Cart with a minimum 200lb./90kg load. A minimum of three passes total are required.

Inlay Method

General Conditions:

- Surface temperature must be 120°F (49°C) - 175°F (79°C)
- Do not attempt to inlay tape during rain.
- Apply tape only after initial compaction has taken place.

Application Procedures:

- Insure general conditions can be met.
- After compaction, mark surface where tape will be applied. DO NOT LAY TAPE ON SEAMS OR JOINTS
- Apply tape either by hand or with the ATM Tape Applicator Cart.
- ALWAYS USE BUTT SPLICES.
- Finish rolling pavement surface.

NOTE: IF TAPE DISTORTS OR WRINKLES, SURFACE TEMPERATURE MAY BE TOO HOT OR ROLLER SPEED MAY BE TOO FAST.

[2] From http://www.trafficmarkings.com/overlay.html