EVALUATION OF INLAID DURABLE PAVEMENT MARKINGS IN AN OREGON SNOW ZONE

Final Report

SPR 304-231

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by

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16. Abstract

The Oregon Department of Transportation (ODOT) evaluated the use of inlaid durable pavement markings within a snow zone. Three different durable pavement marking products were installed and evaluated: Dura-Stripe®, a methyl methacrylate; Permaline®, an alkyd based thermoplastic; and, 3M™ Stamark™ Series 380I Tape, a preformed tape. Each product was applied, at various thicknesses, into a 4 in (102 mm) wide slot ground to various depths. The slot depths were: 250, 180 and 125 mil (6.35, 4.57 and 3.18 mm). The material thickness was varied to achieve a recess from the surface of the pavement of 30 and 60 mil (0.76 and 1.52 mm) below the surface and 10 mil (0.25 mm) above the surface of the pavement. Some sections of the test deck were installed using ODOT's existing specification of a 250 mil (6.35 mm) deep slot completely filled with material and top coated with reflective beads.

After each winter maintenance season the test sections were evaluated based on durability and retroreflectivity. This report summarizes the performance of the test sections after two years in-service. Recommendations about the future use of inlaid durable pavement markings in snow zones are made, including slot and material depth, and material type. A proposed standard for inlaid durable pavement markings is also presented.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
	NOTE: Volumes greater than 1000 L shall be shown in m^3.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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EVALUATION OF INLAID DURABLE PAVEMENT MARKINGS IN AN OREGON SNOW ZONE

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1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

The Oregon Department of Transportation (ODOT) actively monitors and evaluates pavement marking materials in an effort to provide the public with the best performing and longest lasting markings for safety and guidance on Oregon highways. The agency has its own informal committee focusing on striping practices and materials comprised of representatives from throughout ODOT, and from the Oregon Division of the Federal Highway Administration (FHWA). This committee, known as the ODOT Statewide Pavement Marking Committee, became concerned with the poor performance of pavement markings in snow zones throughout the state.

In recent years, ODOT shifted away from using traditional waterborne paints on many of its primary highways in the state. Durable pavement markings have become more prevalent on the state highway system. However, their use in snow zones has been limited. Many ODOT Regions and Districts have been reluctant to use durable pavement markings in snow zones because of past performance issues. The Statewide Pavement Marking Committee theorized that the poor performance of durable pavement markings in central and eastern Oregon centers on the current slot design for inlaid durable pavement markings.

ODOT currently uses a 250 mil (6.35 mm) slot that is backfilled with durable pavement marking material (usually methyl methacrylate) and then topped with a layer of glass beads. The material and beads are approximately 10 mil (0.25 mm) above the surrounding pavement. Winter maintenance activities and the prevalence of studded tires throughout central and eastern Oregon combine to prematurely wear the durable pavement markings to the point where retroreflectivity is prematurely and unacceptably reduced, diminishing the safety benefits. Consequently, the Statewide Pavement Marking Committee partnered with the ODOT Research Unit to initiate research into an alternate slot design that could result in a design that prolongs the life of durable pavement markings in Oregon snow zones.

Additionally, the slot depth of 250 mil (6.35 mm) seemingly was deeper than necessary and may lead to the placement of striping material (and its associated cost) that was never utilized. The question was - could the slot depth be reduced without compromising durability (performance), thereby reducing application costs and in-turn allowing for the placement of more miles of inlaid markings with the available funding.

1.2 RESEARCH OBJECTIVES

The objective of the research project was to investigate and evaluate various inlaid durable pavement marking materials and slot designs used in snow zones on Oregon highways. The research should provide ODOT with a viable slot design for the installation of inlaid durable pavement marking materials in snow zones that will perform as desired and at the most affordable unit price.

The following tasks were undertaken in order to accomplish the research objectives.

1. A literature search to determine the extent and applicability of previous research pertaining to durable pavement markings in snow zones.

2. A field test of different inlaid durable pavement marking materials and various slot designs on both concrete and asphalt pavements.

2.0 LITERATURE REVIEW

Although a significant amount of literature is available on durable pavement markings in general, previous documented research on inlaid durable pavement markings is limited. The following presents a summary of what information was identified, related to inlaid pavement markings and the use of durable pavement markings in snow zones.

2.1 RHODE ISLAND

Lee, Cardi, and Corrigan (*1999*) evaluated the use of inlaid thermoplastic pavement markings on open graded friction course (OGFC) test sections in Rhode Island in response to severely damaged extruded thermoplastic markings from winter maintenance activities. Rhode Island had been using a durable marking design that extruded thermoplastic onto the surface of OGFC pavements at a thickness of 125 mils (3.18 mm). These markings became a target for snow plow blades during winter maintenance activities. In some cases, the cutting edge of the plow blades sheared off the thermoplastic markings, as well as pulled out pieces of the OGFC layers.

Three test sections were selected for the field trial: a 1000 ft (305 m) tangent, a 500 ft (152 m) exit ramp, and a 500 ft (152 m) curved section. Three types of recessed markings were installed, a fully recessed, semi-recessed and tapered recessed. The fully recessed markings were applied flush with the pavement surface in a 125 mil (3.18 mm) slot. The semi-recessed sections were installed in a 1/16 in or 63 mil (1.59 mm) slot with half of the material in the recess and half above the surface of the pavement. The tapered recess skip stripes started with the first 2 in (50 mm) of material in a 125 mil (3.18 mm) slot and tapered up, so that the remaining material was applied to the surface of the pavement.

Based on the analysis and observations, several conclusions were made about the use of recessed thermoplastic pavement markings.

- Visible snow plow blade damage can be reduced by fully recessing thermoplastic pavement markings.

- A statistical analysis revealed no evidence that fully recessing thermoplastic pavement markings reduces the amount of snow plow blade damage to the glass beads.

- Fully recessed thermoplastic markings were found to be cost effective when compared to non-recessed markings. Over the 20 year life cycle cost analysis, the non-recessed markings would need to be replaced six times, while the recessed markings would need to be replaced three times. The three extra replacements, using the non-recessed markings, adds to the vehicle user cost due to traffic delays, but also further increases the risk of safety hazards for more frequently exposed traffic marking replacement crews.

2.2 ALASKA

Connor and Bennett (*2000*) reported on the installation and performance of two test decks near Anchorage and Fairbanks, Alaska. The test decks were comprised of several types of durable pavement markings, including preformed tape and several types of methyl methacrylate products. Each product was surface applied and inlaid. When the report was written the test decks had not been in place long enough to make any firm conclusions. The report did note that previous installations of methyl methacrylate on Alaskan highways had maintained reflectometer readings of 250 millicandellas, three years after initial installation as opposed to traditional solvent-based paint which averaged readings of approximately 100 millicandellas. No update has been made about the performance of the test decks since the interim report from 2000.

2.3 COLORADO

Outcalt (*2004*) evaluated the use of recessed striping on concrete pavement in Colorado. The screed bar of a concrete paver was modified to form grooves for both shoulder and skip stripes on two miles of a 4-lane divided highway. The contractor welded pieces of 0.25 in (6.35 mm) thick steel to the bottom of the screed to form the grooves – 4.5 in (0.11 m) wide for the shoulder stripes and 8 in (0.2 m) wide for the skip stripes. The groove for the skip stripe was made 8 in (0.2 m) to accommodate high visibility black-edged tape.

3M™ Stamark™ Tape was used for both shoulder and skip stripes in the eastbound lanes. All three stripes in the westbound lanes were marked with thermoplastic. Both tape and thermoplastic stripes were stopped at the beginning of the accel/decal lanes and the curved shoulder stripes were marked with epoxy paint. One-year after construction, the grooves were sandblasted to remove all remnants of curing compound, cement slurry, or the temporary epoxy paint.

Both types of pavement markings went through several winters with no noticeable wear from traffic or snowplows. After three winters, all of the tape in the eastbound lanes remained in very good condition. The thermoplastic markings had good retroreflectivity, but some areas had started to crack and separate from the surface of the concrete.

The conclusions from the Colorado study show that placing lane markings in shallow grooves in the pavement results in considerably longer marking life, making the highway safer for drivers. One aspect of this study showed that forming the grooves during construction of the concrete pavement resulted in a nearly cost-free groove – as compared to grinding out a slot.

2.4 WASHINGTON

2.4.1 Benefit/Cost Study

The Transpo Group (*1999*) conducted a pavement markings benefit/cost study for the Washington Department of Transportation (WSDOT). The purpose of the study was to statistically determine the safety benefit of replacing conventional painted pavement markings with durable pavement markings. The analysis was conducted on a section of highway on SR 2 and SR18. Accident data was collected for three years prior to the installation of durable pavement markings, and for three years after the installation.

The accident rates on SR 2 and SR 18 decreased by 38 percent and 16 percent, respectively. Statistical analysis of the results indicates that the accident reduction on SR 2 was significant and could be related to the installation of the durable pavement markings. Based on cost of the durable pavement markings, and the reduction of accidents, the project resulted in a 1.77 to 1 benefit-cost ratio. This indicated that for every dollar WSDOT invests in durable pavement markings on similar roadways, 1.77 dollars of safety benefit to society are extracted from the project.

2.4.2 I-90 Pavement Marking Material Test

Lagregren et al (*2005*) are conducting a test of pavement marking materials on a 40 mile (64.4 km) section of Interstate 90 over Snoqualmie Pass. This section of I-90 traverses the Cascade Mountains and is in a harsh winter weather environment. The harsh conditions, combined with the high traffic volume, make traffic markings problematic. The purpose of this test is to evaluate a variety of "state of the art" materials and installation schemes under different weather and winter maintenance conditions. Materials and installation methods that prove successful in the test may be added to the WSDOT *Standard Specifications* and *Standard Plans* for future use on I-90, as well as other mountain passes in Washington.

A total of seven material manufacturers installed 17 different pavement marking products during September, 2004. Products installed included the following: thermoplastic, methyl methacrylate, preformed tape, polyurea, modified urethane and waterborne paint. Materials were applied in five sections with various pavement and weather conditions. Each material was surface applied as well as applied to inset grooves. Liquid applied materials were applied in a 4 in (102 mm) wide groove and in one of three standardized groove depths of 100, 200 and 300 mil (2.54, 5.08 and 7.62 mm) based on material thickness. Tape materials were applied in a 100 mil (2.54 mm) deep by 4.75 in (121 mm) wide groove. The wider width allowed for ease of straight tape applications within the inset groove. The extra width also allowed for improved tamping of the tape edges.

Based on the test results so far, WSDOT has concluded that there are pavement marking materials and material installation systems that can provide a retroreflective pavement marking on I-90 year round. The completion of the study is scheduled for April 2007.

3.0 TEST DECK DESIGN AND MATERIALS

3.1 RESEARCH METHODOLOGY

The ODOT Statewide Pavement Marking Committee has long been concerned with the performance of pavement markings in snow zones in Oregon. The lack of a visible edge line or skip stripe across mountain passes during winter months is a major safety concern. The wet winter months in Oregon preclude restriping activities in snow zones until drier and warmer weather arrives in the spring and summer months. Durable pavement markings have been installed in some of Oregon snow zones, with mixed results.

The current ODOT standard for inlaid durable pavement markings was based on a similar standard developed by the Washington State Department of Transportation (WSDOT). This design consisted of a slot milled to a depth of 250 mil (6.35 mm) which is then filled with a durable pavement marking material to a level at or above the surrounding pavement. The typical cap, after glass beads were applied to the durable material, was 10 mil (0.25 mm) above the surrounding pavement. Due to winter maintenance activities that shear off the glass beads or de-bond portions of the durable material, the markings performed less than desired.

The research team proceeded in developing a plan for an inlaid durable pavement marking test deck of varying slot and material depths. Although asphalt pavements are the most prevalent type of pavement in Oregon, both asphalt and concrete pavements were desired for the research.

3.2 TEST DECK LOCATION

One of the few regions of the state that has both asphalt and concrete pavements in a snow zone is Eastern Oregon. The research team selected a section of the Old Oregon Trail Highway (Interstate 84) east of Pendleton, Oregon near the small town of Meacham for the site of the test deck. Figure 3.1 shows the approximate location of Meacham, Oregon and the test deck.

Figure 3.1: Location of Meacham, OR and the test deck on I-84

This section of highway encompasses both concrete and asphalt pavement sections and passes through a heavily traveled snow zone corridor with an AADT (Annual Average Daily Traffic) of 9700. The mileposts of the test deck are from 237.33 to 238.69 in the eastbound direction. The area of the test deck is at an elevation of approximately 3700 ft (1129 m), with an average high temperature of 52°F (11°C) and an average low temperature of 35°F (1.7°C). Meacham also receives an average of 148 in (3.76 m) of snow fall per year. Because of the snow fall and the winter weather, the road is subjected to many passes of snow removal equipment including: steel bit snow plows, graders, rotary snow blowers, as well as sanding material and deicing chemicals.

3.3 TEST DECK DESIGN

Both the concrete and asphalt test sections are comprised of 15 sections, 200 ft (61 m) in length, for a total length of 3000 ft (915 m) on each pavement surface. One additional 600 ft (183 m) section on the asphalt pavement was included, as it was adjacent to an exit/gore area.

The ODOT standard of a 250 mil (6.35 mm) slot filled with material served as a control for the study. Shallower slot depths of 180 and 125 mil (4.57 and 3.75 mm) were also included in the test deck. Durable materials were recessed either 30 or 60 mil (0.76 or 1.52 mm) below the pavement surface. Exceptions were made for two waterborne paint test sections that were recessed 95 mil (2.4 mm) below the surrounding pavement. A preformed tape section was also installed and recessed 35 mil (0.889 mm) below the pavement surface. The configuration of the test deck is shown in Table 3.1.

Table 3.1: Test deck configuration

Section Number	Pavement Type	Material	Section Length (ft)	Material Depth (mil)	Slot Depth (mil)	Material-Slot Difference (mil)
1	Concrete	Dura-Stripe	200	260	250	10
2	Concrete	Dura-Stripe	200	220	250	-30
3	Concrete	Dura-Stripe	200	190	250	-60
4	Concrete	Dura-Stripe	200	150	180	-30
5	Concrete	Dura-Stripe	200	120	180	-60
6	Concrete	Dura-Stripe	200	95	125	-30
7	Concrete	Dura-Stripe	200	65	125	-60
8	Concrete	Waterborne Paint	200	30	125	-95
9	Concrete	Permaline	200	95	125	-30
10	Concrete	Permaline	200	65	125	-60
11	Concrete	Permaline	200	150	180	-30
12	Concrete	Permaline	200	120	180	-60
13	Concrete	Permaline	200	260	250	10
14	Concrete	Permaline	200	220	250	-30
15	Concrete	Permaline	200	190	250	-60
16	Asphalt	Dura-Stripe	200	260	250	10
17	Asphalt	Dura-Stripe	200	220	250	-30
18	Asphalt	Dura-Stripe	200	190	250	-60
19	Asphalt	Dura-Stripe	200	150	180	-30
20	Asphalt	Dura-Stripe	200	120	180	-60
21	Asphalt	Dura-Stripe	200	95	125	-30
22	Asphalt	Dura-Stripe	200	65	125	-60
23	Asphalt	Waterborne Paint	200	30	125	-95
24	Asphalt	Permaline	200	95	125	-30
31	Asphalt	3M Stamark 380I Tape	600	90	125	-35
25	Asphalt	Permaline	200	65	125	-60
26	Asphalt	Permaline	200	150	180	-30
27	Asphalt	Permaline	200	120	180	-60
28	Asphalt	Permaline	200	260	250	10
29	Asphalt	Permaline	200	220	250	-30
30	Asphalt	Permaline	200	190	250	-60

3.4 TEST DECK MATERIALS

The following pavement marking materials were installed on the test deck for evaluation.

3.4.1 Dura-Stripe®

Dura-Stripe® is a two-component, methyl methacrylate marking system manufactured by TMT-Pathway®. It can be applied through an extruded process or a spray application. The material for this project was cold applied using a push cart and a shoe to extrude the material into the slot. Dura-Stripe® can be applied at temperatures as low as 30°F (-1°C), which allows for a longer striping season and nighttime operations. The upper threshold for installation is a pavement temperature of 105° F (41°C). The specific product used on the test deck was, Dura-Stripe® Type III (with integral aggregate and glass beads), for use in fully automatic highway striping equipment that is specifically designed for extrusion application. The white material used was lead-free, and the yellow material contained lead.

3.4.1.1 Updated Product Information

After the installation of the test deck, Dura-Stripe was no longer manufactured and was replaced by various formulas using the Dura-Stripe Plus® name. Also, in December 2005 Ennis Paint, Inc. purchased the methyl methacrylate product line (Dura-Stripe Plus®) from TMT-Pathaway®.

3.4.2 Permaline®

Permaline® is an alkyd based thermoplastic pavement marking material manufactured by Ennis Paint, Inc. Permaline® Aggressive Bond, in both white and yellow were applied on the test deck. Thermoplastic can be applied by several methods, including: spray, ribbon extrude, or hot poured. The material used on the test deck was hot poured and applied at temperatures between 400-440°F (201-227°C) depending on air and/or pavement temperature. The white material was lead-free, and the yellow material contained lead.

3.4.3 Stamark™ Series 380I Tape

Stamark™ Series 380I Tape is a conformable, preformed retroreflective tape, containing abrasion-resistant microcrystalline ceramic beads bonded in a polyurethane topcoat. The tape is manufactured by 3M™ and has a patterned surface that presents a near vertical profile to the motorist to maximize retroreflectance and a pliant polymer conformance layer for long term durability. The tape should be applied in air temperatures of 60°F (16°C) and rising and pavement temperatures 70°F (21°C) and rising. Additionally, 3M™ Stamark™ Pavement Preparation Adhesive P50 was applied to the roadway surface prior to the installation of the tape.

3.4.4 Waterborne Paint

The waterborne paint, in both yellow and white, used on the test deck was manufactured by Ennis Paint, Inc. and was the standard waterborne paint used by ODOT’s striping crews. The formula codes for the white and yellow waterborne paint used were the following:

- White – ORW-21-M-4
- Yellow – ORY-21-M-1

3.4.5 Glass Beads

Glass beads were applied to the Dura-Stripe®, Permaline® and waterborne paint during installation. The glass beads used were AASHTO M-247 Type 1 Beads, with a Potters AC02 coating. The beads were manufactured by Potters Industries Inc.

The 3M™ Tape is manufactured with microcrystalline ceramic beads already in-place.

4.0 TEST DECK INSTALLATION

Most of the test deck was installed over a two-week period in late June and early July, 2003. Grinding was done during the week of June 23-27, 2003. Most of the pavement markings were installed June 29-July 2, 2003, except for the 3M™ Tape which was installed July 30, 2003.

Apply-A-Line, Inc, a pavement marking contractor based in the Pacific Northwest performed the grinding for the slots and the installation of the Dura-Stripe® and Permaline® materials. The installation of the 3M™ Tape was performed by representatives from 3M™.

4.1 GRINDING

A gasoline powered pavement scarifier was used to create the 4 in (102 mm) wide slot. Figure 4.1 shows the scarifier in operation on the test deck. Grinding depths were verified to the nearest mil using a Starrett® Dial Depth Gage with a 6 in (152 mm) base, as shown in Figure 4.2. The grinding process was highly variable due to the rough surfaces of both the asphalt and concrete pavement sections, and more variable than desired. Although average slot depths closely matched the target depths, random measurements showed that slot depths varied by as much as 40 mil (1.016 mm) from the target depth in some locations. This was considered acceptable since it was nearly impossible to tighten the tolerances of the pavement scarifier. When grinding the 250 mil (6.35 mm) slot on the asphalt section, two separate passes were used to achieve the target depth. Using one pass at 250 mil (6.35 mm) deep allowed the grinder to be pulled down, resulting in a deeper slot. Two passes were used, the first at 125 mil (3.18 mm) and the second at 250 mil (6.35 mm), to keep the slot closer to the target depth.

Figure 4.1: Wet scarifier in operation on the concrete section of the test deck

Figure 4.2: Starrett® Dial Depth Gage, with a 6 in (15.24 cm) base, used for measuring slot depths

After grinding the slots to the required depths, a mechanical street sweeper was used to clean the slots before the road was opened to traffic.

4.2 MATERIAL INSTALLATION

To prepare the slot for the pavement marking material it was cleaned of dirt and debris. First, a self-propelled shot blaster was used to clean the slot using 7 ½ oz steel shot. Compressed air was then used to remove any dirt or remaining steel shot. It should be noted, that to prepare the slot for the 3M™ Tape, the shot blaster made two passes over the slot. The second pass, smoothed the bottom of the slot to allow better adhesion to the pavement. Figure 4.3 shows the slot just prior to the installation of the Dura-Stripe® and Permaline®. Figure 4.4 shows the slot just prior to the installation of the 3M™ Tape after the second pass with the shot blaster to remove the ridges left from the scarifier blades.

Figure 4.3: Slot just prior to the installation of the Dura-Stripe® and Permaline®

Figure 4.4: Slot just prior to the installation of the 3M™ Tape, after the second pass with the shot blaster

4.2.1 Dura-Stripe® Installation

The installation of the Dura-Stripe® was done at night due to the high pavement temperatures during the daytime. Dura-Stripe® has an upper installation threshold of 105°F (41°C) pavement temperature, which would have been exceeded during the daytime. The material was installed using: a TMT75D applicator to mix the material, a 5D push cart to place the material, and several metal shoes to screed the material to the appropriate depth. The metal screed, when set correctly, screeds the top of the material to the appropriate depth (below the road surface) or height (above the road surface). Three screeds were used during the installation, each set at different depths: 30 and 60 mils (0.762 and 1.524 mm) below the road surface, and 10 mils (0.254 mm) above the road surface. Once the screeds were set correctly, the installation proceeded quickly. However, setting the screeds did take some time and several small test runs were needed to calibrate each screed.

In total, 14-200 ft (61 m) sections of Dura-Stripe® were installed. Of the 14, seven sections on the asphalt pavement had all three lines installed (white edge line, white skip, yellow edge line). The seven sections on the concrete pavement had only the white edge line and the white skip stripe installed. The yellow edge line on the concrete section was not included in the test deck due to the location of the line adjacent to a large joint/crack between the concrete and the asphalt shoulder.

4.2.2 Permaline® Installation

The installation of the Permaline® material was also done at night to coordinate with the Dura-Stripe® installation. The material was installed using two different thermoplastic applicators, an Apollo 1 Pushcart and an Apollo 2 Pushcart, both manufactured by Pavemark. Two different applicators were used, one for white and the other for yellow. A large, truck mounted, pre-melter was also used to melt the white thermoplastic. Since there was less yellow thermoplastic used, it was melted in the applicator pushcart. Figure 4.5 shows the pushcart applicator.

Figure 4.5: Thermoplastic applicator pushcart

One metal shoe was used to apply all of the lines, which was cleaned after each use. Since thermoplastic had not been installed in a protective inlay in Oregon before, a 120 mil (3.05 mm) surface applied shoe was adapted with a metal screed to create the recess. The shoe and screed system were modeled after the system used to install the Dura-Stripe®. The adapted shoe worked for the test deck, but for use in production, a redesigned and more efficient screed system would be needed.

The thermoplastic material was applied at night to correspond with other work being done. During the early morning hours of the thermoplastic installation, moisture (dew) had formed on the asphalt surface. When the hot thermoplastic material was applied to the surface, moisture bubbles formed in the material as it cooled. The moisture bubbles later became voids in the material and accelerated the deterioration of the marking. Dry pavement conditions are critical for the proper installation of all pavement markings, especially hot poured thermoplastic.

4.2.3 3M™ Tape Installation

The installation of the 3M™ Tape was done by two representatives from 3M™. One employee from Apply-A-Line, Inc. was also there to operate the shot blaster to prepare the slot for installation. After shot blasting, compressed air was used to clean the slot. An Adhesive Spray Applicator PS-98 was used to apply a coating of 3M™ P50 Primer Adhesive. The primer was allowed to dry for approximately 10-15 minutes. A Mini Highway Tape Applicator was used to place the tape. A 3M™ Roller Tamper Cart RTC-2, weighing approximately 200 lb (90.8 kg), was then rolled over the tape to ensure proper adhesion. After installation, a vehicle’s tire was then rolled over the tape to further ensure proper adhesion. Figures 4.6-4.8 show the primer applicator, tape applicator, and rolling tamper used during the application.

Figure 4.6: Primer application

Figure 4.7: Tape installation

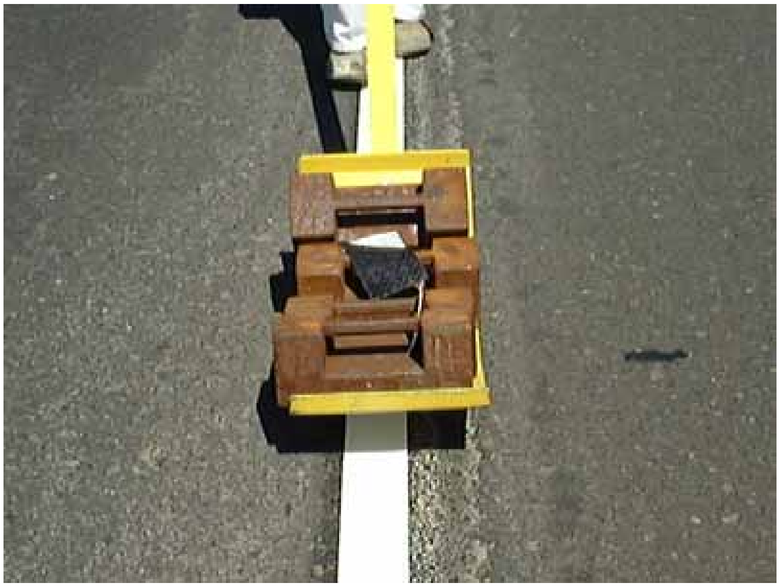


Figure 4.8: Rolling tamper

During the 3M™ Tape installation, care was given to follow the installation recommendations about starting a new role of tape, using a "butt splice". Care was also given to scribe the tape on either side of any large voids created by missing aggregate in the bottom of the slot. During the installation, it was noticed that the tape was slightly wider than the slot and "rolled up" the edge of the slot. After measuring, the slot was slightly under 4 in (100 mm) wide, by 0.063 in (1.6 mm). The 3M™ installation crew decided to continue with the installation of the remaining material, paying particular attention to the narrower slot width.

3M™ Tape was applied in one 600 ft (183 m) section of the test deck. The tape section included 16 skip stripes, and 600 ft (183 m) of yellow edge line. The white edge line was not installed because the section was adjacent to an exit off ramp.

4.2.4 Waterborne Paint

Waterborne paint was applied in 2-200 ft (61 m) sections of the test deck, one on concrete and one on asphalt. The paint was applied in a 125 mil (3.75 mm) slot. White edge line and white skip stripes were applied by ODOT Striping personnel using a push cart handliner and applying the glass beads by hand. The yellow edge line on the asphalt section was applied using ODOT's long-line paint truck. The yellow edge line on the concrete test section was not included in this study.

5.0 EVALUATION OF TEST DECK

The test sections were evaluated shortly after the installation, and each spring for two years after the winter maintenance season was concluded. The test sections were evaluated based on durability and retroreflectivity. Durability was rated as a percent of marking material remaining where ten percent of the number was the rating given for that specific segment of the marking; where as 90% of the material remaining would be a rating of 9. For each marking line, in each section, the durability was rated at 50 ft (15.25 m) intervals. The average of the three ratings per line was used to rate that test section line. Retroreflectivity measurements were also taken to evaluate each of the test sections. All retroreflectivity measurements were taken based on 15 meter geometry (rather than 30 meter geometry).

5.1 AFTER INSTALLATION

All of the materials were installed by August 15, 2003 prior to the start of the winter maintenance season. Because the pavement markings were relatively new, the durability of all lines started at 10, or 100%.

5.1.1 Retroreflectivity

The 31 test sections were designed at 200 ft (61 m) intervals to allow for the use of the Laserlux mobile retroreflectometer to measure the retroreflectivity of each line. However, due to an equipment malfunction and weather conditions, readings were not taken. Alternatively, readings were going to be taken with a handheld retroreflectometer, but due to the weather conditions the readings were not taken.

5.2 AFTER ONE WINTER MAINTENANCE SEASON

In May, 2004, the test sections were evaluated by an inspection team. The lines were assessed based on durability and a measurement of retroreflectivity for each section was attempted. Table 5.1 shows the durability ratings of each section and line after one winter maintenance season.

Table 5.1: Summer 2004 - Durability assessment of each line after one winter maintenance season

Test Section	Pavement Type	Material	Material Depth (mil)	Slot Depth (mil)	Material-Slot Difference (mil)	Durability Rating		
						Yellow Edgeline Avg	Skips Avg	White Edgeline Avg
1	Concrete	Dura-Stripe	260	250	10	NA	10	10
2	Concrete	Dura-Stripe	220	250	-30	NA	10	9.8
3	Concrete	Dura-Stripe	190	250	-60	NA	9.5	9.7
4	Concrete	Dura-Stripe	150	180	-30	NA	10	9.8
5	Concrete	Dura-Stripe	120	180	-60	NA	10	10
6	Concrete	Dura-Stripe	95	125	-30	NA	8.5	6.8
7	Concrete	Dura-Stripe	65	125	-60	NA	8.5	6.7
8	Concrete	Waterborne Paint	30	125	-95	NA	4.7	3
9	Concrete	Permaline	95	125	-30	NA	0.3	0
10	Concrete	Permaline	65	125	-60	NA	0.2	0
11	Concrete	Permaline	150	180	-30	NA	4.3	4.7
12	Concrete	Permaline	120	180	-60	NA	0	0
13	Concrete	Permaline	260	250	10	NA	7.7	0.3
14	Concrete	Permaline	220	250	-30	NA	3.2	7.2
15	Concrete	Permaline	190	250	-60	NA	1	1.3
16	Asphalt	Dura-Stripe	260	250	10	10	9.7	10
17	Asphalt	Dura-Stripe	220	250	-30	10	10	10
18	Asphalt	Dura-Stripe	190	250	-60	9	10	10
19	Asphalt	Dura-Stripe	150	180	-30	9	9	9
20	Asphalt	Dura-Stripe	120	180	-60	9	10	9
21	Asphalt	Dura-Stripe	95	125	-30	9	8.8	7.5
22	Asphalt	Dura-Stripe	65	125	-60	9	8.7	7.7
23	Asphalt	Waterborne Paint	30	125	-95	8.3	3.7	0
24	Asphalt	Permaline	95	125	-30	7.7	6.5	0
25	Asphalt	Permaline	65	125	-60	8.5	7.3	0.2
26	Asphalt	Permaline	150	180	-30	9	8.5	8
27	Asphalt	Permaline	120	180	-60	9	7	5.3
28	Asphalt	Permaline	260	250	10	10	8.7	9.7
29	Asphalt	Permaline	220	250	-30	9.5	6.7	9.5
30	Asphalt	Permaline	190	250	-60	9.5	7.7	9.7
31	Asphalt	3M Tape	90	125	-35	9.5	9	NA

5.2.1 Concrete Sections

5.2.1.1 Permaline®

Table 5.1 shows that the Permaline® material on the concrete pavement did not perform well after one winter maintenance season. Large portions of the material were missing from the white edge line. Figure 5.1 shows the thermoplastic white edge line in Section 11, which had a durability rating of 4.7. Figure 5.2 shows the white edge line in Section 14, which was rated the highest for the Permaline® concrete sections, at 7.2.

Figure 5.1: Section 11 – Permaline®, on concrete edge line, after one winter maintenance season

Figure 5.2: Section 14 – Permaline®, on concrete edge line, after one winter maintenance season

The Permaline® skip stripes on the concrete pavement performed similar to the white edge line, with some of the skips retaining more material than the edge line. Figure 5.3 shows a skip in Section 11, which averaged 4.3. Figure 5.4 shows a skip in Section 13, which averaged 7.7. The white edge line for Section 13 did not perform well and was essentially non-existent. However, the skip stripe performed the best out of the Permaline® sections on the concrete, with an average rating of 7.7.

Figure 5.3: Section 11 - Permaline®, on concrete skip, after one winter maintenance season

Figure 5.4: Section 13 - Permaline®, on concrete skip, after one winter maintenance season

5.2.1.2 Dura-Stripe®

Table 5.1 shows that the Dura-Stripe® material was fairly consistent after one winter maintenance season. Two sections did not perform well when compared to the other five. Sections 6 and 7 were constructed using the shallow slot depth of 125 mil (3.18 mm). The skips were rated at 8.5 and the edge line averaged near 7. The remaining sections averaged approximately 10, for both the skips and edge line. Figures 5.5 and 5.6 show the lines in Section 4.

Figure 5.5: Section 4 – Dura-Stripe®, on concrete, after one winter maintenance season

Figure 5.6: Section 4 – Close-up of Dura-Stripe®, on concrete edge line, after one winter maintenance season

5.2.1.3 Other Materials

Waterborne traffic paint was used in one section on the concrete pavement. The paint was applied into a 125 mil (3.18 mm) deep slot at thickness of approximately 30 mil (0.76 mm). After one winter maintenance season, the paint was barely visible and not effective. The performance of the paint is typical of other ODOT paint applications in this snow zone. In some locations where the paint was applied, the 125 mil (3.18 mm) slot was not visible.

5.2.2 Asphalt Sections

All three lines were included on the asphalt section; white edge, yellow edge, and skips.

5.2.2.1 Permaline®

The Permaline® sections on the asphalt performed better than those on the concrete pavement, after one winter maintenance season. The yellow edge line was rated higher for all sections, compared to the white edge line or the skips. This is likely due to less wheel traffic on the line, and less pavement loss. There was a clear distinction between the deeper 250 mil (6.35 mm) slot designs compared to the other sections. The three sections that used the 250 mil (6.35 mm) slot (Sections 28, 29, 30) performed better than the other four sections. Figures 5.7 and 5.8 show the white edge line and skip in Section 28 which used the deeper slot.

Figure 5.7: Section 28 – Permaline®, on asphalt skip, after one winter maintenance season

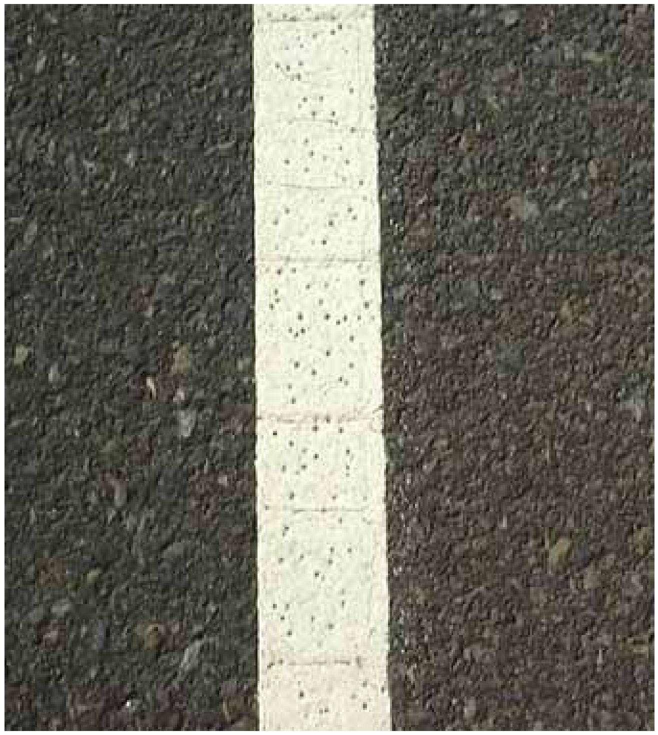


Figure 5.8: Section 28 – Close-up of Permaline®, on asphalt skip, after one winter maintenance season

5.2.2.2 Dura-Stripe®

The seven sections of Dura-Stripe® on the asphalt pavement performed similarly to the sections on the concrete pavement. The sections on the asphalt were fairly consistent, with the exception of the two sections designed with the 125 mil (3.18 mm) slot. The other five sections, for all three lines, averaged a rating of approximately 10. Figures 5.9 and 5.10 show the white edge line in Section 17.

Figure 5.9: Section 17 – Dura-Stripe®, on asphalt edge line, after one winter maintenance season

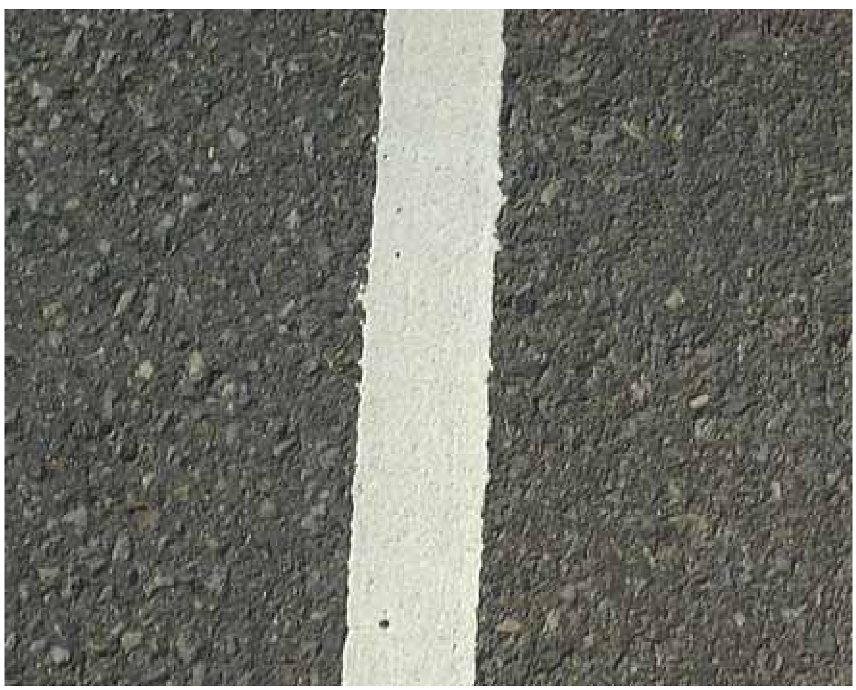


Figure 5.10: Section 17 – Close-up of Dura-Stripe®, on asphalt edge line, after one winter maintenance season

5.2.2.3 3M™ Tape

3M™ Tape was applied to the yellow edge line and to the skip stripe in one-600 ft (183 m) section on the asphalt pavement. After one winter maintenance season the material performed very well, as shown in Figure 5.11. One 10 ft (3.05 m) skip had been damaged shortly after installation, losing approximately 3ft (1 m) of material. The yellow edge line had almost no damage. The tape did however flatten-out, as shown in Figure 5.12.

Figure 5.11: Section 31 – 3M™ Tape, on asphalt yellow edge line, after one winter maintenance season

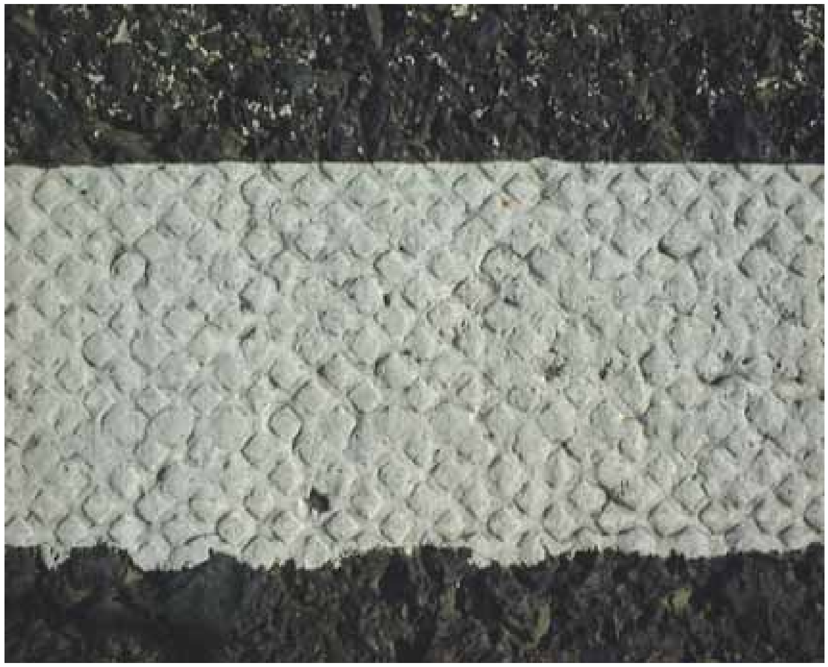


Figure 5.12: Close-up of a 3M™ Tape skip, after one winter maintenance season

5.2.2.4 Other Materials

Waterborne traffic paint was used in one section on the asphalt pavement. The paint was applied into a 125 mil (3.18 mm) slot at approximately 30 mil (0.762 mm) thickness. After one winter maintenance season, the white paint on the white edge line and skips was barely visible and not effective, which is typical of ODOT’s paint applications in this snow zone. In some locations where the paint was applied, the slot was not visible after one year. The yellow paint applied to the yellow edge line was still visible and performing much better than the white paint.

5.2.3 Retroreflectivity

Retroreflectivity measurements were attempted after one winter maintenance season. Again, the mobile retroreflectometer, or Laserlux, was tried. Due to the measurement constraints and distance measuring device of the Laserlux, it was unable to precisely catalog the start and end point of each 200 ft (61 m) section. Since the Laserlux produces an average measurement, without saving the raw data, a correction factor could not be applied. Due to the late fall weather, retroreflectivity measurements could not be taken with a handheld retroreflectometer either.

5.3 AFTER TWO WINTER MAINTENANCE SEASONS

In June, 2005 the test sections were again evaluated by an inspection team. The lines were assessed based on durability and a measurement of retroreflectivity for each section and line was taken. Table 5.2 shows the durability ratings of each section and line, after two winter maintenance seasons.

Table 5.2: Summer 2005 - Durability assessment of each line after two winter maintenance season

Test Section	Pavement Type	Material	Material Depth (mil)	Slot Depth (mil)	Material-Slot Difference (mil)	Durability Ratings		
						Yellow Edgeline Avg	Skips Avg	White Edgeline Avg
1	Concrete	Dura-Stripe	260	250	10	NA	9	9
2	Concrete	Dura-Stripe	220	250	-30	NA	9	9
3	Concrete	Dura-Stripe	190	250	-60	NA	9	9
4	Concrete	Dura-Stripe	150	180	-30	NA	9	9
5	Concrete	Dura-Stripe	120	180	-60	NA	9	9
6	Concrete	Dura-Stripe	95	125	-30	NA	7.8	7.7
7	Concrete	Dura-Stripe	65	125	-60	NA	7.3	6
8	Concrete	Waterborne Paint	30	125	-95	NA	0	0
9	Concrete	Permaline	95	125	-30	NA	0	0
10	Concrete	Permaline	65	125	-60	NA	0	0
11	Concrete	Permaline	150	180	-30	NA	0	0
12	Concrete	Permaline	120	180	-60	NA	0	0
13	Concrete	Permaline	260	250	10	NA	3.2	0
14	Concrete	Permaline	220	250	-30	NA	0	4.8
15	Concrete	Permaline	190	250	-60	NA	0	0
16	Asphalt	Dura-Stripe	260	250	10	9	8.7	9
17	Asphalt	Dura-Stripe	220	250	-30	9	9	9
18	Asphalt	Dura-Stripe	190	250	-60	9	8.7	8.8
19	Asphalt	Dura-Stripe	150	180	-30	9	9	7
20	Asphalt	Dura-Stripe	120	180	-60	9	8.5	7.5
21	Asphalt	Dura-Stripe	95	125	-30	9	8.8	5.5
22	Asphalt	Dura-Stripe	65	125	-60	8.7	6.7	6
23	Asphalt	Waterborne Paint	30	125	-95	8	0	0
24	Asphalt	Permaline	95	125	-30	7.7	6.5	0
25	Asphalt	Permaline	65	125	-60	7	7.2	0
26	Asphalt	Permaline	150	180	-30	8	7.7	6.2
27	Asphalt	Permaline	120	180	-60	7.7	6.8	0
28	Asphalt	Permaline	260	250	10	8	6.3	8.2
29	Asphalt	Permaline	220	250	-30	9	4.6	7.8
30	Asphalt	Permaline	190	250	-60	8	6.5	8.3
31	Asphalt	3M Tape	90	125	-35	9	9	NA

5.3.1 Concrete

5.3.1.1 Permaline®

The Permaline® sections of material on the concrete pavement continued to perform poorly. After two winter maintenance seasons, most of the material was missing. Sections 13 and 14 were the only sections with any material remaining, but even that was limited. Section 14, as shown in Figure 5.13, had some material still visible, but not enough to be effective.

Figure 5.13: Section 14 – Permaline®, on concrete white edge line, after two winter maintenance seasons

5.3.1.2 Dura-Stripe®

After two winter maintenance seasons, the Dura-Stripe® sections on the concrete pavement changed little since the year one evaluation. Based on the rating of the skips, section one through five ranged 8.8 to 9.2. For the white edge line they all ranked 9.0. Sections 6 and 7, with the 125 mil (3.18 mm) slot depth, rated lower at 6.7 to 7.8. Figure 5.14 shows the white edge line of Section 3 after two winter maintenance seasons.

Figure 5.14: Section 3 – Dura-Stripe®, on concrete edge line, after two winter maintenance seasons

5.3.2 Asphalt

5.3.2.1 Permaline®

The Permaline® sections on the asphalt pavement rated lower after the second year of winter maintenance. Again, the sections with the 125 mil (3.18 mm) slots were rated lower than the other five sections. Sections 26, 28, 29 and 30 were rated the highest, with an average rating between 7.6-7.1. It should be noted that the yellow edge line was rated higher than either the skips or the white edge line, for all seven sections. Figure 5.15 shows the yellow edge line in Section 30, and Figure 5.16 shows the white edge line.

Figure 5.15: Section 30 – Permaline®, yellow edge line on asphalt, after two winter maintenance seasons

Figure 5.16: Section 30 – Permaline®, white edge line on asphalt, after two winter maintenance seasons

During the installation of the Permaline® on the asphalt pavement, moisture bubbles formed in the material. The moisture bubbles were caused by the increased humidity during the time of installation. The material was applied between 3:00 am and 5:00 am, when a noticeable amount of dew had formed. When the hot thermoplastic was placed on the asphalt pavement, moisture bubbles formed. After two years, the moisture bubbles, combined with the shrinking of the thermoplastic, created cracks and voids in the line. The cracks can be seen in Figure 5.16

5.3.2.2 Dura-Stripe®

The Dura-Stripe® sections on the asphalt pavement still had good physical presence after two winter maintenance seasons. Again, the two 125 mil (3.18 mm) sections were rated lower than the other five sections. All three lines in Section 17 were rated an average of 9. The other four sections ranged in averaged ratings from 8.9-8.3. Figures 5.17 and 5.18 show the white edge line and yellow edge line in Section 17. For the five sections (16, 17, 18, 19 and 20) that rated the highest, all of the yellow edge lines were rated 9.0 and were very consistent.

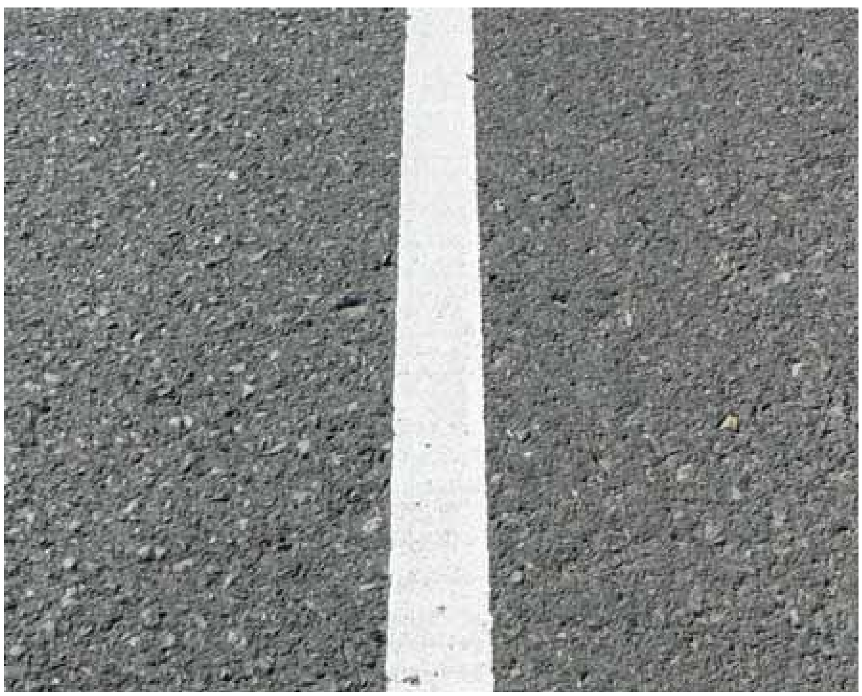


Figure 5.17: Section 17 – Dura-Stripe®, white edge line on asphalt, after two winter maintenance seasons

Figure 5.18: Section 17 – Dura-Stripe®, yellow edge line on asphalt, after two winter maintenance seasons

5.3.2.3 3M™ Tape

After two winter maintenance seasons, the 3M™ Tape still had good physical presence and was rated 9.0, for both the yellow edge line and the skips. One additional skip was damaged after the second year of service, losing approximately 5% of material from the 10 ft (3.05 m) skip. Figures 5.19 and 5.20 show the 3M™ Tape after two winter maintenance seasons.

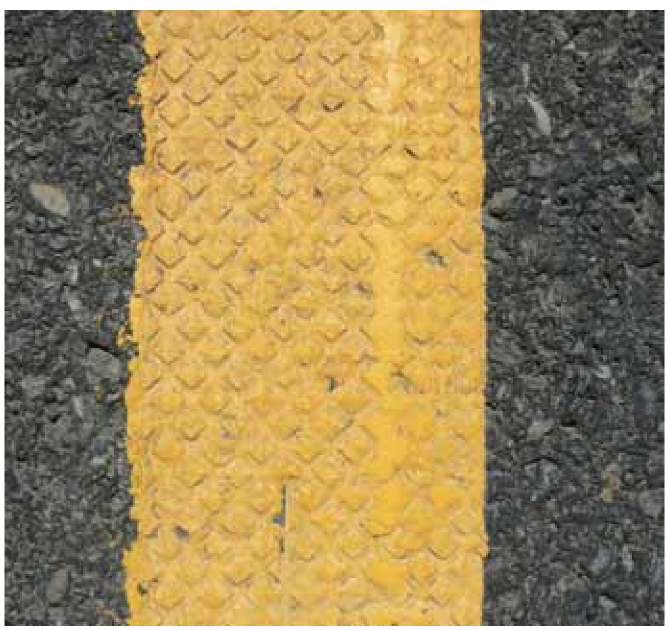


Figure 5.19: Section 31 – 3M™ Tape, yellow edge line on asphalt, after two winter maintenance seasons. The smooth line, on the right side of the tape, was a result of the high ridge left by the grinder.

Figure 5.20: Section 31 – 3M™ Tape, skip on asphalt, after two winter maintenance seasons

5.3.2.4 Other Materials

The white edge line and skips installed with waterborne paint were not visible after one winter maintenance season. However, the waterborne paint on the yellow edge line was still visible after two winter maintenance seasons. Figure 5.21 shows the yellow edge line in Section 23, which was rated 8.0.

Figure 5.21: Section 23 – Waterborne Paint, yellow edge line on asphalt, after two winter maintenance seasons

5.3.3 Retroreflectivity

When taken, the retroreflectivity readings were collected using a Mirolux MP-12, a portable 15 meter retroreflectometer. For each line, in each section, five readings were taken at 50 ft (15.25 m) increments: at 50, 100, and 150 ft (15.25, 30.5 and 45.75 m) from the start point. The location of the measurements corresponds to the location of the durability ratings as well. The 15 retroreflectivity measurements were then averaged. Table 5.3 presents the retroreflectivity readings for the 31 test sections, taken after two years of service.

Table 5.3: Summer 2005 - Retroreflectivity readings after two winter maintenance seasons

Test Section	Pavement Type	Material	Material Depth (mil)	Slot Depth (mil)	Material-Slot Difference (mil)	Retroreflectivity Values		
						Yellow Edgeline Avg	Skips Avg	White Edgeline Avg
1	Concrete	Dura-Stripe	260	250	10	NA	126	72
2	Concrete	Dura-Stripe	220	250	-30	NA	134	76
3	Concrete	Dura-Stripe	190	250	-60	NA	120	101
4	Concrete	Dura-Stripe	150	180	-30	NA	126	95
5	Concrete	Dura-Stripe	120	180	-60	NA	119	104
6	Concrete	Dura-Stripe	95	125	-30	NA	125	101
7	Concrete	Dura-Stripe	65	125	-60	NA	122	89
8	Concrete	Waterborne Paint	30	125	-95	NA	no line	no line
9	Concrete	Permaline	95	125	-30	NA	no line	no line
10	Concrete	Permaline	65	125	-60	NA	no line	no line
11	Concrete	Permaline	150	180	-30	NA	no line	no line
12	Concrete	Permaline	120	180	-60	NA	no line	no line
13	Concrete	Permaline	260	250	10	NA	no line	no line
14	Concrete	Permaline	220	250	-30	NA	no line	161
15	Concrete	Permaline	190	250	-60	NA	no line	no line
16	Asphalt	Dura-Stripe	260	250	10	40	82	75
17	Asphalt	Dura-Stripe	220	250	-30	64	78	84
18	Asphalt	Dura-Stripe	190	250	-60	68	80	82
19	Asphalt	Dura-Stripe	150	180	-30	71	89	73
20	Asphalt	Dura-Stripe	120	180	-60	74	78	72
21	Asphalt	Dura-Stripe	95	125	-30	79	84	65
22	Asphalt	Dura-Stripe	65	125	-60	65	72	64
23	Asphalt	Waterborne Paint	30	125	-95	83	49	no line
24	Asphalt	Permaline	95	125	-30	56	100	no line
25	Asphalt	Permaline	65	125	-60	76	104	no line
26	Asphalt	Permaline	150	180	-30	72	95	144
27	Asphalt	Permaline	120	180	-60	71	91	no line
28	Asphalt	Permaline	260	250	10	59	102	147
29	Asphalt	Permaline	220	250	-30	94	81	138
30	Asphalt	Permaline	190	250	-60	96	86	153
31	Asphalt	3M Tape	90	125	-35	196	94	NA

6.0 SUMMARY AND RECOMMENDATIONS

The results of the pavement marking test deck showed that any pavement marking material placed in a snow zone in Oregon is put through a great deal of abuse. Based on the performance of the test deck, several observations can be made about the installation of inlaid pavement markings in snow zones, the slot depths, material thickness and overall performance. Recommendations can also be made about the future use of inlaid pavement marking materials in snow zones.

6.1 INSTALLATION

6.1.1 Slot Installation

The grinding of the slot is a key factor during the installation of inlaid markings. Much attention should be given to the control of the grinding equipment. Appropriate depth should be maintained and inspected on a regular basis. During the grinding process, the depth varied depending on the overall depth of the cut and the pavement type. For instance, to maintain a uniform depth for the 250 mil (6.35 mm) slot on the asphalt pavement, two passes had to be made – the first at 125 mil (3.18 mm) and the second at 250 mil (6.35 mm). Due to the rough surface of the concrete pavement it was very difficult to accurately measure the depth of the slot. An average of several measurements was used to try and maintain a uniform depth, but with limited success.

6.1.2 Slot Preparation

To prepare the slot for installation of the marking materials, a mechanical sweeper was used to remove the grinding materials. A steel shot blaster was then used to create a more even surface at the bottom of the slot and to remove an remaining grinding material. Compressed air was then used to remove any excess dust and dirt, and remove any steel shot remaining from the blasting operation. This process was especially crucial for the installation of the 3M™ Tape. Any large amounts of debris in the slot would have weakened the adhesion to the pavement.

6.1.3 Material Placement

6.1.3.1 Permaline®

Several observations were made during the installation of the Permaline® markings. Since this was the first time that a thermoplastic material was inlaid in Oregon, the applying contractor altered the existing equipment to inlay the material. This system worked for the test deck, but for production work the shoe screed would need to be refined. The temperature of the thermoplastic proved to be the determining factor in maintaining a consistent depth of material within the slot and for producing a quality line.

Material too high in temperature was very fluid and spread easily. Material too low in temperature was very difficult to screed to the appropriate depth. Temperature is also critical for proper glass bead placement - too high and the beads sink to deep, too low and the beads do not get properly imbedded.

The amount of moisture also proved to be crucial for proper thermoplastic installation. Because the thermoplastic white edge lines on the asphalt were placed in the early morning hours, moisture (dew) had formed on the asphalt surface. When the hot material was placed on the asphalt, small moisture bubbles formed in the material. After the material cooled, the bubbles created voids in the line and formed weak points for cracking. Care should be given to installing all materials, especially thermoplastic, in dry pavement conditions.

6.1.3.2 Dura-Stripe®

The installation of the Dura-Stripe® went fairly well. Uniform material thickness was achieved using three different application shoes, set at different screed depths. The screeds were adjusted after transitioning from the concrete pavement to the asphalt pavement, due to the different surface textures. Due to the rough texture of the concrete surface, the slot and material depths were more difficult to maintain.

6.1.3.3 3M™ Tape

The installation of the 3M™ Tape went smoothly. A second pass with the steel shot blaster was needed to provide a smoother slot surface. Care was given to follow the 3M™ installation guidelines, including the use of “butt splices” to properly end and start a new roll of material. Proper adhesion was achieved using the approved primer adhesive and through proper compaction.

6.2 PERFORMANCE

The performance of the materials used on the test deck was based mostly on the durability ratings of the test sections. Comparing the performance of the materials based on retroreflectivity measurements is not applicable due to the lack of data. Originally, retroreflectivity data was to be collected each year after the winter maintenance season, but due to equipment and scheduling problems the data was not collected.

6.2.1 Permaline®

The Permaline® sections did not perform well on the concrete pavement. De-bonding occurred within one year of service. Large portions of the material were missing with only small portions of the 4 in (102 mm) line remaining. After two years of service, none of the thermoplastic sections on the concrete pavement had enough material remaining to provide a sufficient pavement marking.

The Permaline® performed much better on the asphalt pavement surface. The material on the yellow edge line performed better than the either the white edge line or the skip line. Based on the performance of the white edge line material, the three sections with the thickest material depth performed the best. Based on the performance of the yellow edge line material, all of the material performed well, with the thickest material performing the best.

The Permaline® material placed on the asphalt surface developed cracks after one year of service. After two years of service, the cracks had raveled out and created large gaps in the line, especially on the white edge line. The moisture bubbles in the material also developed into larger voids, which also reduced the performance of the line.

6.2.2 Dura-Stripe®

When compared to the performance of the Permaline® markings, the Dura-Stripe® markings performed better and were more consistent throughout the test deck. The sections that used the 125 mil (3.18 mm) slot, on both concrete and asphalt, did not perform as well as the 180 or 250 mil (4.57 or 6.35 mm) slot designs. The thin amount of material did not provide enough substance to withstand the abuse over two years. The remaining sections performed better, providing more sufficient markings after two years of service.

The Dura-Stripe® material placed on the yellow edge line of the asphalt pavement performed better than the skip line or the white edge line. This could be attributed to the shift in traffic to the right, towards the wider shoulder. Based on the limited measurements of retroreflectivity for the Dura-Stripe® material, the two sections that used the 125 mil (3.18 mm) slot performed lower than the other sections. The retroreflectivity data also showed a slight decline for the sections that provided no recess, a 250 mil (6.35 mm) slot slightly overfilled with material. Although not enough retroreflectivity data was taken to determine the statistical significance of the data.

6.2.3 3M™ Tape

The 3M™ Tape performed well on the yellow edge line and the skip line where it was installed. After two years of service, 2 of the 16 skips were damaged. One skip was missing portions of material shortly after installation and 5% of the second skip was missing between the first and second year of service. The yellow edge line did not lose any material during the two years of service.

The 3M™ Tape applied to the yellow edge line measured much higher than the other materials based on retroreflectivity. When measured, the skips were comparable to the other materials tested, based on retroreflectivity.

6.3 RECOMMENDATIONS

Based on the performance of the test deck, the following recommendations are made about the future use of inlaid durable pavement markings in snow zones.

6.3.1 Inlaid Design

For inlaid Dura-Stripe® applications, a 200 mil (5.08 mm) slot depth is recommended to be filled with 150 mil (3.81 mm) of material, leaving a 50 mil (1.27 mm) recess for the protection of the material and the glass beads. The 200 mil (5.08 mm) slot filled with 150 mil (1.27 mm) of material was not tested on the test deck, but it was a “balancing” of the slot and material designs that were tested. The 125 mil (3.18 mm) slot design did not perform well, and the test deck showed that the Dura-Stripe® material did not need to be inlaid into a 250 mil (6.35 mm) slot to perform well. By reducing the depth of the slot to 200 mil (5.08 mm) and reducing the amount of material, it should lower the cost of the material and decrease the amount of time for installation. Appendix A shows the new standard drawing for the inlaid durable pavement markings.

The 3M™ Tape performed well on the test deck, based on both durability and retroreflectivity performance. Although not used on the white edge line, or on the concrete pavement, it did perform well on the yellow edge line and the skip line on the asphalt pavement. Inlaid into a 125 mil (3.18 mm) slot, the material performed very well. Based on the results of the test deck, it is recommended that 3M™ Tape be considered for more inlaid applications on asphalt pavements within snow zones. More testing may be needed to evaluate the use of it inlaid on concrete pavements.

Based on the test deck performance, hot poured inlaid Permaline® material is not suitable for use on concrete pavement surfaces in snow zones. Their use, inlaid, on asphalt pavement surfaces may have potential, but will require additional research and testing. Under better installation conditions (without the presence of moisture) the 250 mil (6.35 mm) slot, with 190 or 220 mil (4.83 or 5.59 mm) of material, may perform better and provide a sufficient pavement marking. However, the use of hot poured thermoplastic on the asphalt pavement yellow edge line did perform much better than the white edge line or skips. Installed on tangent sections of roadway, the use of hot poured thermoplastic inlaid markings may perform sufficiently on the yellow edge line with a similar slot design as shown in Appendix A; 200 mil (5.08 mm) slot filled with 150 mil (1.27 mm) of material.

6.3.2 Installation

The grinding and material application equipment could not consistently meet the slot depth and material depth specifications over the course of the project. It is recommended that greater attention be given to the quality of installation, specifically to the depth of the slot and to the thickness of the material.

For this research project, a dial depth gage was used to measure the slot depth and the protective recess from the surface of the pavement to the top of the material. The use of the dial depth gage may not be practical for field use by contractors or ODOT Inspectors. During the course of this project, a simple depth gage was designed by ODOT’s Traffic Line Personnel. Figure 6.1 shows the three gages designed to measure the depth of inlaid slots and the amount of material recess from the surface of the pavement. The gages were designed for depths of 50, 100, 150, 200, 250 mil (1.3, 2.55, 3.8, 5, 6.35 mm). One gage also includes a depth of 875 mil (22.2 mm) which is the ODOT Specification depth for inlaid reflective pavement markers. The gages also include markings to measure the width of the line, up to 4 in (102 mm).

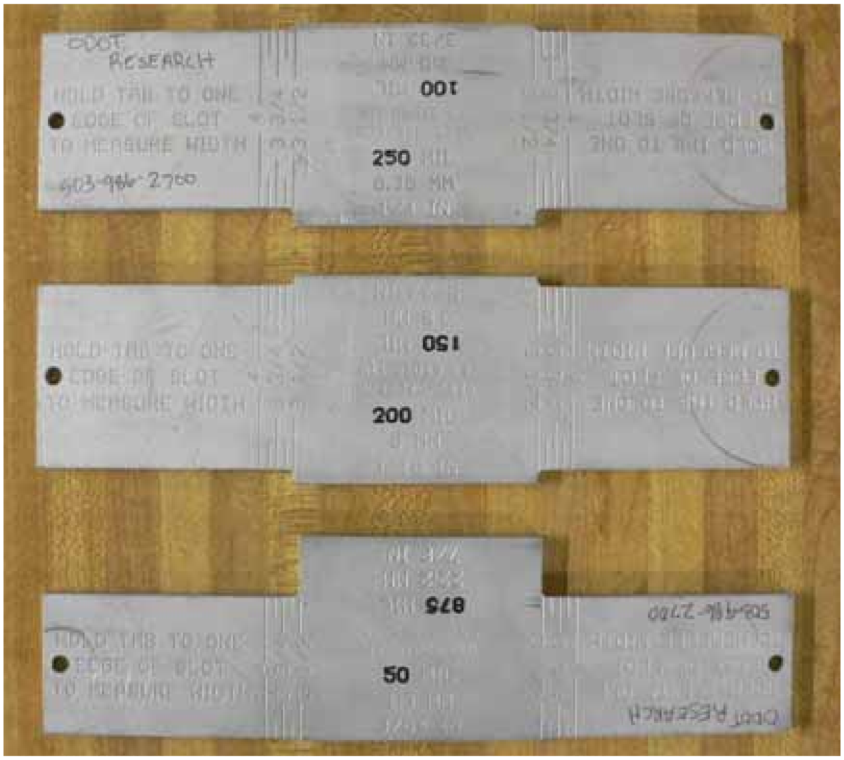


Figure 6.1: Metal gauges to measure slot depth and material recess.

6.4 RECOMMENDED FUTURE RESEARCH

The test deck for this project will continue to be evaluated after each winter maintenance season until all of the sections and products fail. Future research on the use of durable pavement markings in Oregon snow zones could include the following areas:

- Evaluate the use of 3M™ Tape inlaid on concrete pavements in snow zones.
- Evaluate methods to repair and maintain inlaid 3M™ Tape in snow zones.
- Evaluate the performance of spray applied thermoplastic markings inlaid on both asphalt and concrete surfaces.
- Evaluate the wet weather performance of durable pavement marking products and the effects of water “ponding”.
- Evaluate the performance of inlaid durable pavement markings using the 200 mil (5.08 mm) slot depth and the 150 mil (1.27 mm) material thickness.

7.0 REFERENCES

Connor, B. and J. Bennett. 2000. *Selection of Pavement Marking Materials.* Alaska Department of Transportation and Public Facilities. Research and Technology Transfer. Report No. FHWA-AK-RD-00-01.

Lagergren, E., J. Bertsch, and D. Fernald. 2005. *WSDOT I-90 Pavement Marking Material Test-Interim Report.* Washington Department of Transportation.

Lee, K., S. Cardi, and S. Corrigan. 1999. *Implementation and Evaluation of Traffic Marking Recesses for the Application of Thermoplastic Pavement Markings on Modified Open Graded Friction Course.* New England Transportation Consortium. Report No. URI-CVET-97-2.

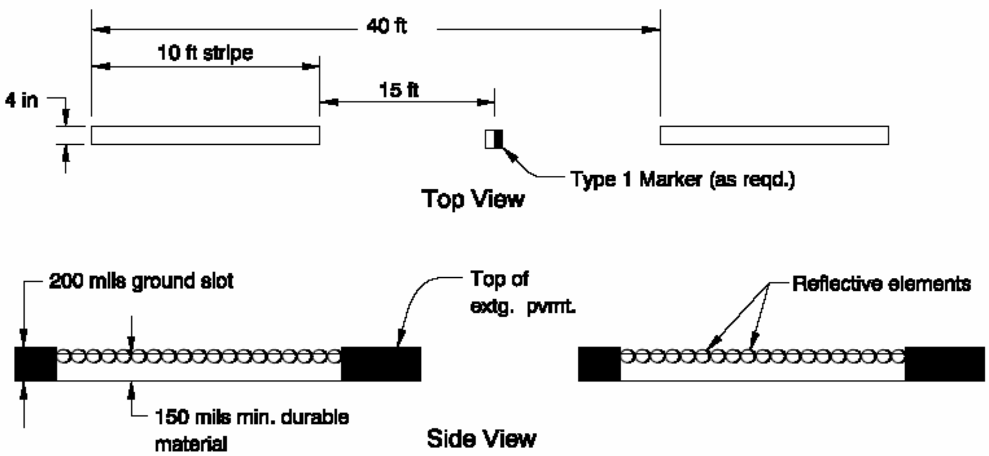
Outcalt, W. 2004. *Recessed Striping in Concrete Pavement*. Colorado Department of Transportation, Research. Report No. CDOT-DTD-R-2004-13.

The Transpo Group. 1999. *Pavement Markings Benefit/Cost Study*. Kirkland, Washington.

APPENDIX A

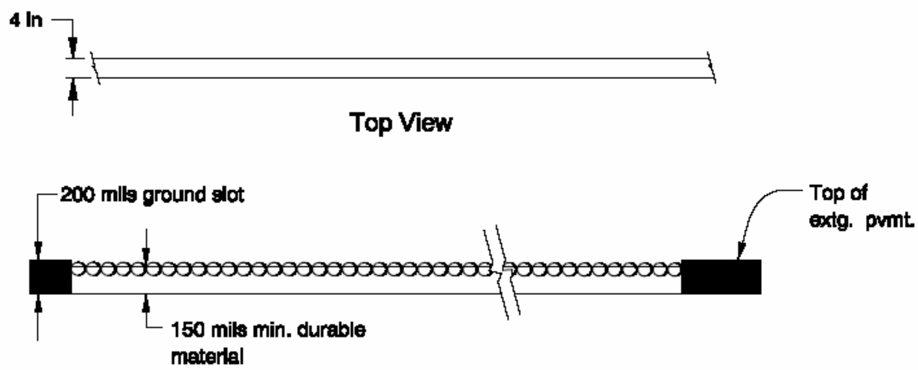
INLAID DURABLE PAVEMENT MARKING STANDARD DRAWING

DURABLE PAVEMENT MARKINGS
METHOD 'C' PROTECTED INLAID



Skip Line

Note: Reflective elements (Top Coating) shall be imbedded into the durable material 50% of the bead diameter and shall be flush with/to slightly recessed below pavement surface.



Solid Line

The selection and use of this Standard Drawing, while designed in accordance with generally accepted engineering principles and practices, is the sole responsibility of the user and should not be used without consulting a Registered Professional Engineer.

NOTE: All material and workmanship shall be in accordance with the current Oregon Standard Specifications

OREGON STANDARD DRAWING

PROPOSED

DURABLE PAVEMENT MARKINGS
METHOD "C" INLAID

2002

REVISIONS	
DATE	DESCRIPTION
11-02	Added Protected inlaid details
06-06	Changed depth of slot and material thickness

TM521