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16. Abstract

This report describes the tasks of a study conducted to identify effective pavement marking materials and application procedures on Portland cement concrete (PCC) roadways in Texas. The researchers reviewed relevant literature, reviewed data from the National Transportation Product Evaluation Program (NTPEP), surveyed state departments of transportation, surveyed material manufacturers, and analyzed cost-effectiveness of various materials.

Based on findings from the research tasks, the researchers generated a number of recommendations for pavement markings on PCC roadways in Texas, which include:

- Use epoxy materials for long-term applications under the majority of traffic conditions,
- Use preformed tape for long-term applications under very heavy traffic, and
- Use TxDOT specification thermoplastic only for short-term applications with low to medium traffic.

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EFFECTIVE PAVEMENT MARKING MATERIALS AND APPLICATIONS FOR PORTLAND CEMENT CONCRETE ROADWAYS

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This project was conducted in cooperation with TxDOT and the Federal Highway Administration. The authors would like to thank the project director, Greg Brinkmeyer of the TxDOT Traffic Operations Division, for providing guidance and expertise on this project.

The authors would also like to thank all of the state DOT and pavement marking industry personnel who provided survey information for this report. The authors would especially like to thank Mujeeb Basha from American Association of State Highway and Transportation Officials (AASHTO) and David Kuniega from Pennsylvania DOT for their assistance with NTPEP reports and data interpretation.

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CHAPTER 1:
INTRODUCTION

In September 2000, the Texas Transportation Institute (TTI) began a three-year research project sponsored by the Texas Department of Transportation (TxDOT) to evaluate pavement markings. The goal of Project 0-4150, Evaluation of Pavement Marking Effectiveness, was to improve the performance and cost-effectiveness of pavement markings used on Texas highways.

The performance of long-line pavement markings on Portland cement concrete (herein referred to simply as concrete or PCC) roadway surfaces has become a major issue for TxDOT. Concrete is used sparingly for pavements in rural areas where hot-mix asphalt and surface treatments are more economical and more easily constructed. Concrete is much more likely to be used for roadway surfaces in urban areas and on higher-type roadways, resulting in much higher traffic volumes when compared to asphalt roadways. Table 1 and Figures 1 and 2 display TxDOT centerline and vehicular mileages and percentages by pavement surface type and roadway classification (*1*).

Table 1. TxDOT Lane Mileage by Roadway Class and Surface Type.

Roadway Type and Mileage		*Asphalt (Including Surface Treatments)*		*PCC*		*Total Miles*
		Miles	%	Miles	%	
Interstate Hwy	Centerline Miles	6594	85	1147	15	7741
	Vehicle Miles (x 1,000)	95,113	67	46,878	33	141,991
U.S. Hwy	Centerline Miles	12,631	94	794	6	13,425
	Vehicle Miles (x 1,000)	83,037	77	25,446	23	108,483
State Hwy	Centerline Miles	15,953	95	836	5	16,789
	Vehicle Miles (x 1,000)	82,915	79	22,332	21	105,246
Farm-to-Market Hwy	Centerline Miles	40,777	99	218	1	40,994
	Vehicle Miles (x 1,000)	57,580	95	3085	5	60,665
TOTAL	**Centerline Miles**	**75,955**	**96**	**2995**	**4**	**78,950**
	Vehicle Miles (x 1,000)	**318,645**	**77**	**97,740**	**23**	**416,385**

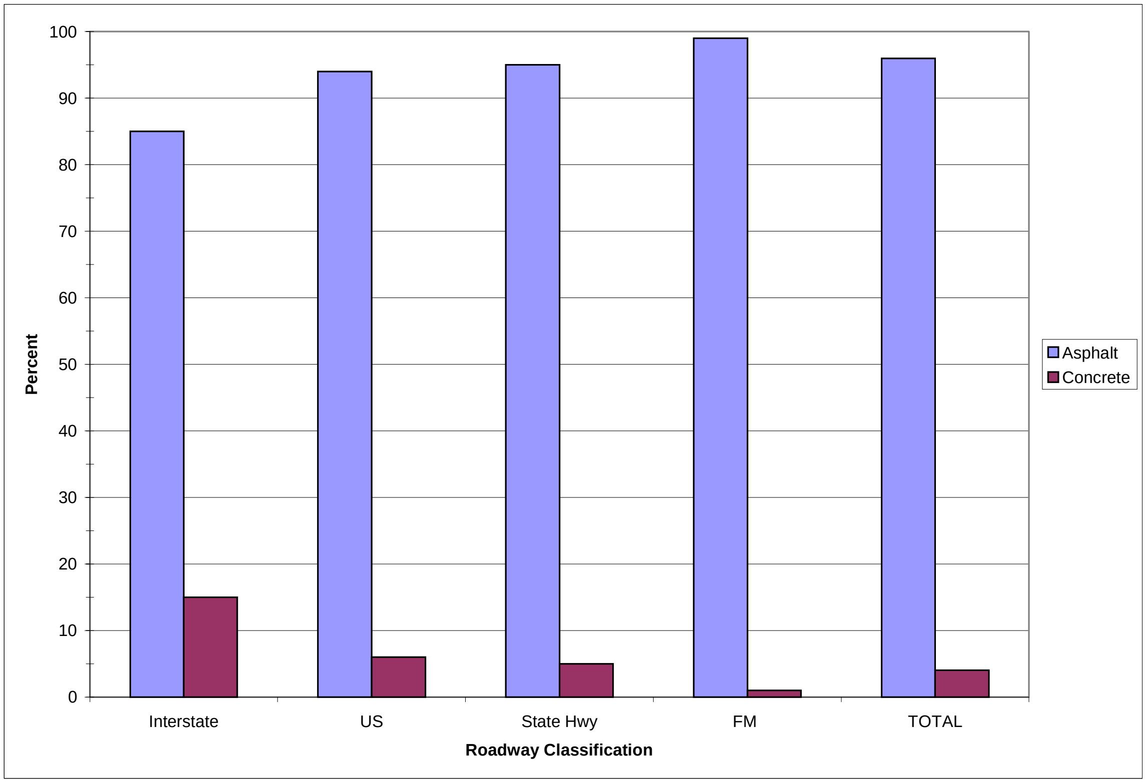

Figure 1. TxDOT Centerline Mileage for Asphalt vs. Concrete.

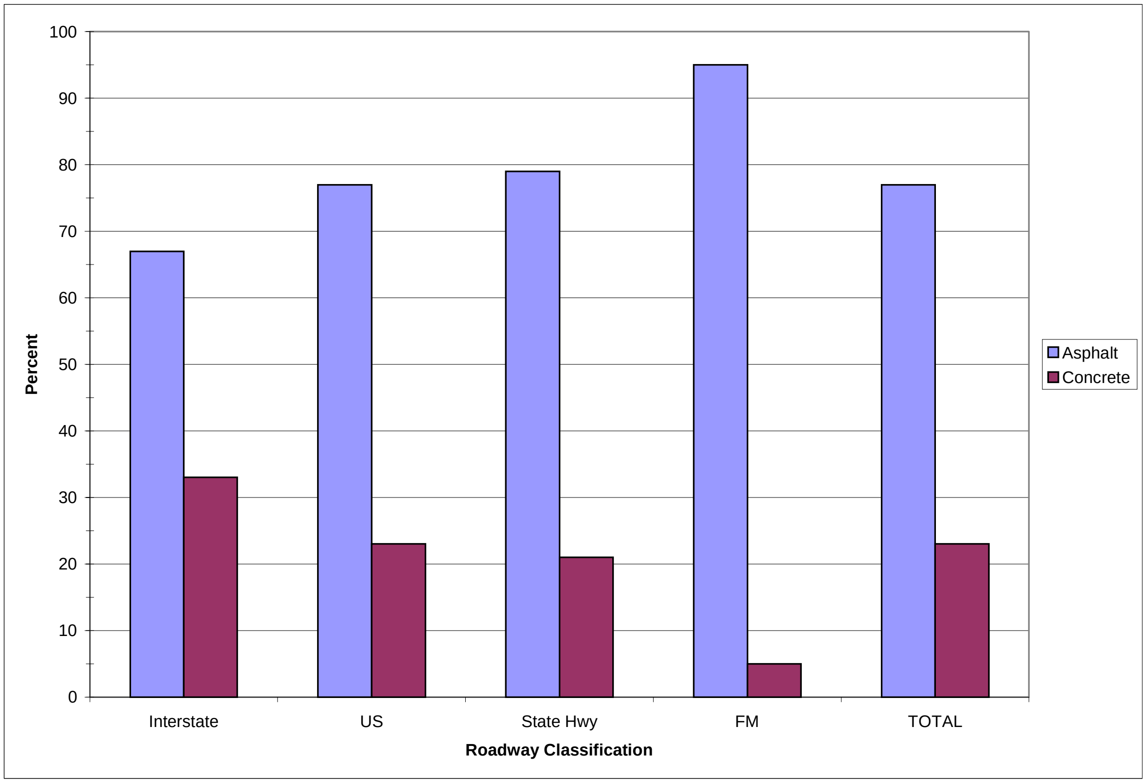

Figure 2. TxDOT Vehicle Miles Traveled for Asphalt vs. Concrete.

The preceding table and figures show that while only a small percentage of TxDOT's centerline mileage (4 percent) is concrete, the concrete roadways carry nearly one-quarter of the traffic. As such, engineering-related issues involving TxDOT's concrete roadways should not be ignored.

PAVEMENT MARKING PERFORMANCE MEASURES

Many materials exist that may be used for pavement markings on concrete roadway surfaces. However the service life and cost of the various materials vary greatly. As with other traffic control devices, maintaining pavement markings that are highly visible and long lasting presents a major challenge to transportation agencies.

In general, pavement marking performance is judged by two criteria: durability and visibility (*2*).

- ***Durability*** refers to the amount of material remaining on the pavement surface over time. Durability affects both the daytime and nighttime appearance of markings. Durability performance is often measured either by determining the percentage of material remaining on the surface or by directly testing the bond strength of a material to the surface.
- ***Visibility*** relates to the brightness of the material. Visibility is particularly a nighttime performance measure when the retroreflective properties of the markings greatly influence their ability to be seen. Daytime visibility is related to the contrast of the marking with the pavement surface. Much of the research concerning marking visibility uses retroreflectivity as a proxy measure for visibility performance.

It is important to recognize that most pavement marking materials do not provide equal durability and visibility under every roadway situation. Performance for a specific material may vary widely based on many factors, including roadway surface type, traffic volume, and environment/weather. Each of these factors must be considered when selecting the optimum pavement marking material for a given set of roadway, traffic, and environmental circumstances.

PROBLEM STATEMENT

Some TxDOT districts have been experiencing premature de-bonding of pavement marking materials on concrete roadways. Until recently, TxDOT commonly used non-retroreflective ceramic buttons for lane lines on urban concrete roadways statewide. Ceramic buttons were a popular pavement marking material because they provided better durability on concrete pavement surfaces than most other commonly used pavement marking materials in Texas. Ceramic buttons usually achieve service lives of at least two years on concrete under the harshest traffic conditions. Button service lives of four years or more are common under less severe traffic conditions. While buttons provide suitable *durability* on concrete, they do not provide *retroreflectivity*, and thus provide minimal visibility under headlamp illumination at night[1], although continuous roadway lighting is common on most TxDOT urban freeways. Until May 2000, buttons were allowed for use as permanent striping application when used in conjunction with retroreflective raised pavement markers (RRPMs). However, recognizing the lack of retroreflectivity provided by ceramic buttons, in May 2000, TxDOT officials revised the Signs and Markings Volume of the TxDOT Traffic Operations Manual strongly discouraging the use of buttons:

> *Since the non-reflective buttons do not increase nighttime or wet weather reflectivity and can become a maintenance problem when installed in high volume traffic areas, they should not be used to simulate striping patterns on permanent installations (3).*

Although more than two years have passed since this policy change, TxDOT has not widely used a marking material that consistently matches the durability of ceramic buttons on concrete. Sprayed alkyd thermoplastic conforming to TxDOT material specification DMS 8220 has been the most commonly used material on concrete and remains the most popular pavement marking material in Texas regardless of surface type. A 2002 survey of TxDOT districts by Hawkins and Gates confirmed the popularity of thermoplastic in Texas, finding that out of 14 responding districts (both rural and urban), only four districts had experimented with materials other than waterborne paint and thermoplastic for longlines[2].

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[1] Retroreflective raised pavement markers are placed at 40-ft or 80-ft spacing between consecutive lane lines to provide supplemental positional guidance at night.

[2] Unpublished survey information. Epoxy, preformed permanent tape, and polyurea were the only other materials experimented with by the four districts.

The durability of thermoplastic on concrete roadways has become a major issue for TxDOT, especially in some urban districts. On numerous occasions, TxDOT officials have observed thermoplastic materials de-bonding from concrete roadways earlier than expected for applications with both primed and unprimed surfaces. Thermoplastic de-bonding is especially common in Texas on concrete roadways with high traffic volumes, traffic weaving, or high moisture/humidity conditions, with de-bonding occurring as early as six months after application. Other materials have shown similar results. Some experimental materials have been successful, but TxDOT has limited experience and data to support widespread use. With more than 12,000 concrete lane miles maintained by TxDOT, carrying nearly one-quarter of the traffic (Table 1), TxDOT should use a pavement marking material on concrete that will provide appropriate levels of durability and visibility.

OBJECTIVE AND TASKS

The issue of the most appropriate pavement marking materials for concrete roadways has been discussed on numerous occasions, including at both of the TTI-TxDOT pavement marking conferences, but there has been little scientific evaluation of the available information. TTI researchers conducted several tasks to help TxDOT identify the pavement marking materials that are best suited for use on concrete roadways. These tasks are listed below and are described in more detail in the next section of this chapter:

- Reviewing the available literature about pavement marking materials for concrete pavements.
- Reviewing the results of National Transportation Product Evaluation Program (NTPEP) evaluations of pavement marking materials on concrete pavements.
- Surveying selected state departments of transportation (DOTs) to determine the marking materials most commonly used in other states.
- Surveying material manufacturers to identify the available products and the manufacturer recommendations for marking materials on concrete surfaces.
- Analyzing the cost-effectiveness of various materials.

Of particular interest were materials and corresponding application procedures that provide a minimum marking service life of four years on concrete pavements under severe environmental and traffic conditions. This report details the findings resulting from the major tasks. Each of the major materials that can be used on concrete is addressed in individual chapters. Each chapter presents the findings from all of the tasks as they relate to the specific material of the chapter. The final chapter presents overall findings and recommendations regarding the use of pavement marking materials on concrete roadways.

TASK DESCRIPTIONS

The information presented in the succeeding chapters about various marking materials was obtained through several tasks as described below.

Literature Review

Researchers performed a review of the literature to identify previous research pertaining to the performance of various pavement markings on concrete roadways. This included literature sponsored and/or published by state and federal transportation agencies. Journal articles were also included in the literature review. TTI researchers were particularly interested in research performed within the last decade, as pavement marking specifications and formulations are modified frequently.

NTPEP Evaluations

NTPEP is responsible for testing and evaluating products, materials, and devices that are commonly used by the American Association of State Highway and Transportation Officials (AASHTO) Member Departments of Transportation. NTPEP is a major resource for comprehensive pavement marking evaluations performed at the national level. The lead agency collects laboratory and field performance data for products included in the evaluation and compiles them into a report. Although data are furnished within the report, no approval, disapproval, or endorsements of products are made per NTPEP/AASHTO policy. Reports are made available to member agencies and other interested parties. TTI researchers obtained and reviewed the following three recent NTPEP pavement marking reports:

- 2000 Urban California Test Deck (first year data), Report 02 NTPEP 216 (*4*);
- 2000 Pennsylvania Test Deck (first year data) [3], Report 02 NTPEP 221 (*5*); and
- 1999 Mississippi Test Deck (second year data), Report 02 NTPEP 220 (*6*).

[3] Unpublished second year data were obtained by TTI from PennDOT and were used for material evaluation.

Each of the three reports was obtained because the evaluations included the most up-to-date pavement marking materials on concrete roadway surfaces. The California report was of particular interest, due to the high traffic volumes through the test sections. A more detailed description of the NTPEP data sources can be found in Appendix A.

TTI research staff analyzed retroreflectivity and durability data taken from each of the three NTPEP decks at the end of the second year[4] (*4*,*5*,*6*). TTI research staff rated each of the 313 total materials as "*good*," "*marginal*," or "*poor*" based on a combination of the retroreflectivity and durability performance on concrete pavements. Particular attention was paid to material performance in the wheelpath due to the accelerated wear placed on the markings. TTI researchers were especially interested in materials that had been evaluated in more than one of the reports. Similar performance of a material from one report to another would potentially serve to validate findings. Unfortunately, only 23 of the 313 total materials (7.3 percent) included in the three NTPEP reports obtained by TTI had been evaluated in more than one of the reports.

State DOT Survey

In summer 2002, TTI research staff surveyed 19 state DOTs to determine current practices and experiences concerning pavement marking materials on high traffic-volume concrete roads. The goal of the survey was to determine specific materials and corresponding application procedures that have been found to provide a minimum marking service life of four years on concrete pavements under the most severe traffic and environmental conditions. States with various pavement marking practices and challenges throughout the United States were included in the survey. Researchers selected states to participate in the survey based on whether one or more of the following criteria were met:

- presence of personnel currently involved in national pavement marking issues;
- presence of a hot, humid climatic region; or
- presence of at least one major metropolitan area.

The survey consisted of four concise questions and was initially sent via email to the 19 DOT contacts in mid-June 2002. The complete survey form along with detailed agency responses can be found in Appendix B. A note was added to the email stating that TTI research

[4] Only first-year data were analyzed from the California deck.

staff would telephone each state within a few weeks to retrieve the survey answers. TTI staff retrieved the survey answers via telephone between late-June and late-July 2002.

The state DOT personnel were asked several questions pertaining to pavement markings placed on roadways with the highest average daily traffic (ADT), including: types of materials, contracted costs, application procedures, service lives, and problems that have been encountered with each type of material on concrete. Researchers asked DOT personnel to name the material that provides the best long-term performance on the high-ADT concrete roadways within their agency's jurisdiction. Agencies cited experience with the following materials on high-ADT concrete, either through frequent or experimental use:

- epoxy,
- preformed tape,
- thermoplastic,
- polyurea,
- waterborne paint,
- modified urethane, and
- polyester.

Industry Survey

The manufacturers of pavement marking materials maintain a wealth of knowledge about the performance of specific pavement marking materials on all types of pavement surfaces. TTI research staff surveyed 14 pavement marking material manufacturers to determine top-performing pavement markings material on high traffic-volume concrete roads. The survey consisted of four concise questions and was sent via email to the 14 industry contacts in mid-June 2002. The complete survey form can be found in Appendix C. The goal of the survey was to determine detailed information about specific materials and corresponding application procedures for use on concrete under the most extreme traffic and environmental conditions. Of particular interest were specific materials and application procedures recommended both by the DOTs and material manufacturers for use under such conditions.

Cost-Effectiveness Analysis

Cost-effectiveness analyses are commonly used methods for relative comparison of the costs of various alternatives. Engineers often rely on cost-effectiveness analyses to assist in decision-making for various construction alternatives. These analyses are useful because they take into account not only the initial costs of the alternatives, but also the service lives of the alternatives and the costs incurred throughout the service lives.

Methodology

An elementary cost-effectiveness analysis was performed for the pavement marking materials described in this report. The analysis performed herein took into account the following factors for each material:

- contracted costs (per linear foot)
  - material application,
  - surface preparation,
  - removal of existing markings, and
- expected material service life.

Researchers obtained contracted material application costs in one of two ways:

- For materials with a TxDOT bid item (e.g., thermoplastic, tape, and paint), the 12-month statewide average low-bid construction price was used[5].
- For materials without TxDOT bid items, information from other state DOTs and material manufacturers were used to develop application cost estimates.

Contracted surface preparation and marking removal cost estimates were obtained from 12-month statewide average low-bid construction prices for Item 678-0515 and Item 677, respectively. Material service life estimates were based on information obtained from TxDOT, other state DOTs, and material manufacturers.

Total life-cycle costs were computed for each material. Dividing the total life-cycle cost by the expected service life provided for normalization of the life-cycle costs into units of dollars per linear foot per year. The results of the cost-effectiveness analysis are included in the descriptions of the individual materials found later in this report. User delay costs were not

[5] 12-month statewide low-bid construction average for 4-inch white solid on September 18, 2002.

included in the analysis due to the variations in traffic demands statewide. Because each cost component used in the analysis was in present dollars, interest costs were not included.

CHAPTER 2:
THERMOPLASTIC

Thermoplastic pavement marking materials have been used in the United States since 1958 and consist of four basic components: binder, pigment, glass beads, and filler (sand or calcium carbonate). TxDOT has used thermoplastic pavement markings for many years, with use increasing over the past 10 years. As a result, the vast majority of the longitudinal pavement marking miles on TxDOT roadways are thermoplastic. Thermoplastic pavement markings are the most heavily used pavement marking materials in Texas for a number of reasons, including:

- material availability,
- contractor availability,
- reasonable cost, and
- good performance.

Thermoplastic pavement marking materials are widely recognized for superior performance on asphalt roadways. Recently however, users have questioned the durability of thermoplastic pavement markings on concrete.

TEXAS THERMOPLASTIC

Thermoplastic materials are classified by TxDOT as a Type I pavement marking material. TxDOT currently uses a "recipe" alkyd thermoplastic specification for standard sprayed thermoplastic applications (*7*). Although other thermoplastic formulations and application processes are allowed and are sometimes used by TxDOT districts through special provision, TxDOT specification thermoplastic applied by spray method is most often used. Due to the widespread use of TxDOT specification thermoplastic (DMS 8220) on concrete pavements in Texas, data pertaining to TxDOT specification thermoplastic on concrete will serve for baseline comparison for all other materials. Data for TxDOT specification thermoplastic exist in Table 2.

Table 2. Characteristics of TxDOT Specification Thermoplastic When Used on Concrete.

Initial Contracted Material Cost ($/LF)	Total Life Cycle Cost ($/LF)	Typical Service Life (years)	Total Cost per Year of Service Life ($/LF/yr)	Surface Preparation	No-Track Time (sec)	Lane Closure Reqd.?
0.20	0.66	2	0.33	Blast Clean[a], Primer is Necessary	30	No

[a] Full removal of existing markings is required if markings are de-bonding from the pavement, if the restripe and existing materials are not compatible, or if the marking profile is too thick.

PERFORMANCE ON CONCRETE

Many factors influence the performance of thermoplastic markings. Pavement surface type, surface preparation, air and material temperatures, and pavement moisture can all be crucial factors in the performance of thermoplastic markings. Thermoplastic materials usually perform very well on asphalt surfaces of all types (including sealcoats) and are highly recommended for use on those surfaces. Unfortunately, this performance is often not achieved on concrete pavements due to premature de-bonding of the material from the roadway surface.

Bonding Capabilities

The major difference in thermoplastic bonding capabilities between asphalt and concrete surfaces is based on the bonding mechanism. Thermoplastic materials bond to asphalt through a thermal-bonding process in which the thermoplastic material fuses into the pavement surface at the contact point. The thermal-bonding mechanism creates a very tight bond between the thermoplastic and asphalt, often stronger than the cohesive strength of the asphalt material itself.

Unfortunately, thermoplastic does not bond to concrete in the same way. Bonding with concrete surfaces is achieved solely by mechanical bonding. Mechanical bonding occurs when the molten thermoplastic material seeps into the pores of the concrete and solidifies, creating an interlocking mechanism. The strength of mechanical bonding is generally less than thermal bonding. As a result, less force is required to remove the thermoplastic material from concrete than asphalt. Thermoplastics often de-bond from concrete surfaces by cracking and then flaking off from the surface. This often occurs as a result of stresses induced by contraction and expansion of the concrete, greatly weakening the mechanical bond and causing the marking to crack.

Thermoplastic manufacturers suggest that certain thermoplastic formulations are better suited to withstand the contraction/expansion stresses and subsequent de-bonding induced by the concrete. To help alleviate these problems, manufacturers have suggested thermoplastic materials that are less stiff/more flexible and possess aggressive concrete-bonding capabilities. These materials are less likely to experience the cracking/flaking/de-bonding problems that often occur with other thermoplastics on concrete surfaces. These materials may provide a service life of four years on concrete under heavy traffic conditions. Limited field data exist on the performance of these thermoplastic products, although their use is increasing on concrete roadways in Texas.

Florida Thermoplastic/Concrete Adhesion Study

Florida International University recently performed (1999) a detailed comparison of the bonding capabilities of thermoplastic materials with both asphalt and concrete pavements. This research project came as a result of Florida DOT's experience with thermoplastic de-bonding from concrete roadways six to eight months after application. The researchers were particularly interested in comparison of the bonding strengths obtained on concrete vs. asphalt when different surface preparations were used (*8*). The goal was to provide a recommendation on whether the bonding strength between concrete and thermoplastic was strong enough to justify its use on PCC pavements.

The following surface preparations were included in the evaluation for both pavement types (please note that all concrete surfaces were coated with an epoxy primer before thermoplastic markings were installed):

- no additional surface preparation prior to epoxy primer and thermoplastic application (control),
- waterblasting prior to epoxy primer and thermoplastic application,
- grinding/scarifying prior to epoxy primer and thermoplastic application,
- sandblasting prior to epoxy primer and thermoplastic application, and
- wire brushing prior to epoxy primer and thermoplastic application.

Researchers measured the bonding strength one week after marking placement with a portable pull-off adhesion tester using the procedures in ASTM D4541-95[6]. Markings were

[6] The adhesion tester measures the greatest perpendicular force a bond can bear immediately prior to failure.

considered to be in new condition at the time of testing since they had not been exposed to traffic. Grinding/scarifying of the pavement surface produced the strongest bond for both asphalt and concrete surfaces (242 and 216 psi, respectively). Figure 3 shows comparisons of the adhesion strengths for thermoplastic achieved for different surface preparations on both asphalt and concrete.

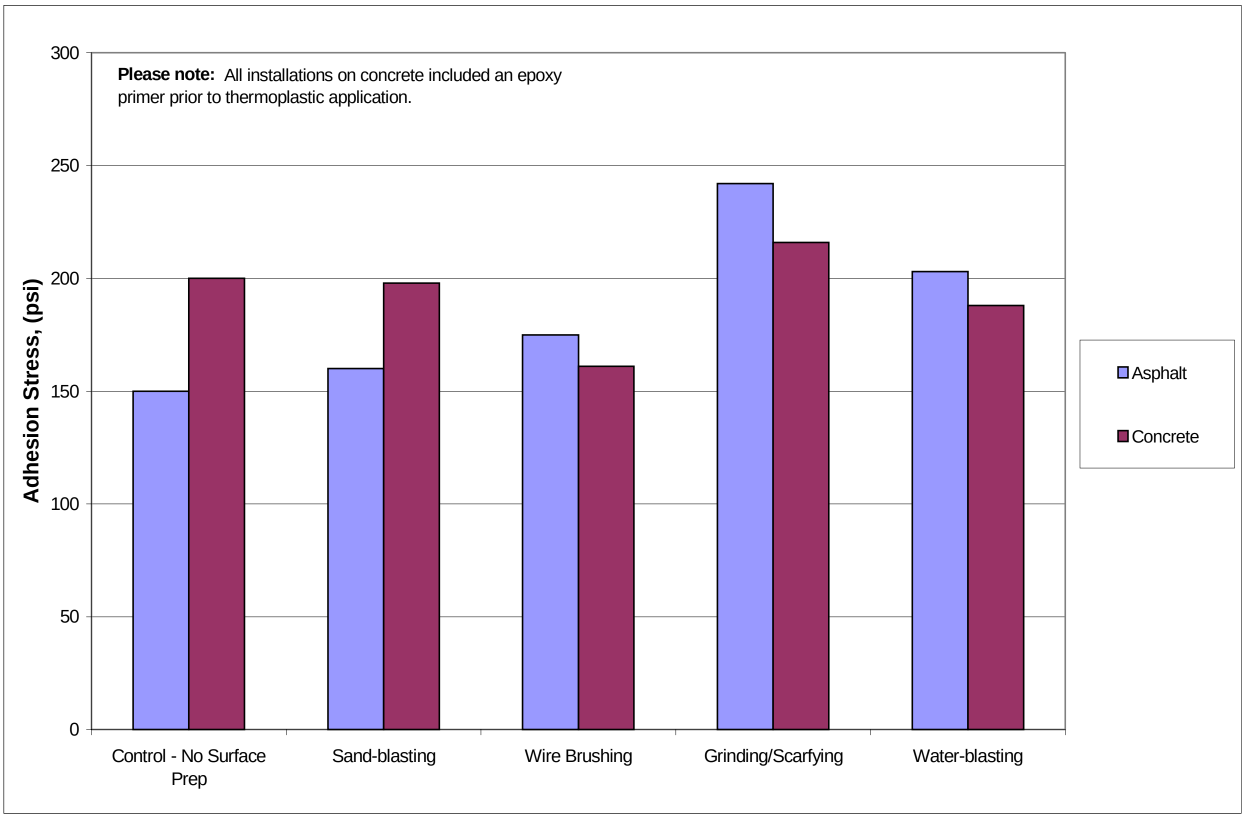

Figure 3. Thermoplastic Adhesion Stress as a Function of Surface Type and Preparation.

Figure 3 displays that, for the most part, thermoplastic provided about the same bonding strength on both asphalt and concrete surfaces, with results varying slightly based on surface preparation. The findings suggest that favorable thermoplastic adhesion can be achieved on PCC surfaces if an epoxy primer is used. The researchers in this study suggested a similar study performed after the markings had been in place for one year to determine the degradation of the material/surface bonds over a longer period of time. They concluded that the results of this study did not warrant the recommendation to discontinue thermoplastic pavement marking use on PCC pavements.

NTPEP Performance

Recent NTPEP testing has also shown favorable results for some thermoplastic materials on concrete. As described in Chapter 1, TTI research staff rated each of the NTPEP thermoplastic materials as "*good*," "*marginal*," or "*poor*" based on a combination of the retroreflectivity and durability performance on concrete pavements at the end of the second year. Table 3 displays the top performing thermoplastic materials from the recent NTPEP reports reviewed by TTI.

Table 3. Top Performing Thermoplastic Materials on Concrete Pavements (NTPEP).

Manufacturer	Product Number	NTPEP Location	Thick-ness (mil)	Primer/ Sealer	Bead Type[a]	Bead App. Rate[b]	Bead Coating[c]
Avery Dennison[d]	W5E5GXTB (Permaline)	Penn.	101-124	None	PT 260	10	MP
Avery Dennison[d]	W4D5GXVA (Pavemark)	Penn.	86-92	None	VA Spec	10	MP
Cataphote	XT37104201	Penn.	68-90	None	AASHTO	10	None
Crown	01-WAX-BADA	Penn.	99-153	Tuff Tak	AASHTO	10	MP
Crown	06-WAX-AICF	Penn.	100-153	Tuff Tak	AASHTO	10	MP
Crown	40-WAX-BADA	Penn.	85-164	Tuff Tak	PT 260	10	MP
Crown	Tuffline Alkyd	Miss.	N/A	N/A	N/A	N/A	N/A
Crown	01-WEX-BADA	Miss.	N/A	N/A	N/A	N/A	N/A
Ennis	ET4-AK-SX-W-1	Penn.	94-111	None	PA Spec	Flood	MP
		Cal.	100	None	N/A	Flood	N/A
Ennis	ET4-HY-SX-W-1	Penn.	84-109	None	PA Spec	Flood	MP
Ennis	AA-AK-SX-W-1	Miss.	N/A	N/A	N/A	N/A	N/A
Ennis	AA-AK-TLS-W-1	Miss.	N/A	N/A	N/A	N/A	N/A
Lafarge	LRM00T-10	Penn.	84-96	None	PA Spec	Flood	MP
Lafarge	LRM00T-11	Penn.	150	Eptac	PA Spec	Flood	MP
Lafarge	LRM99-130	Miss.	N/A	N/A	N/A	N/A	N/A
Lafarge	LRM99-132	Miss.	N/A	N/A	N/A	N/A	N/A
Lafarge	LRM99-135	Miss.	N/A	N/A	N/A	N/A	N/A
Swarco	VAWA001	Penn.	65-77	Swarco 318	VA Spec	Flood	None

Notes: Information based on 2001-2002 NTPEP Deck Data.
NTPEP does not provide endorsement to any of the products listed in this table.
N/A = Data not available in NTPEP report.
[a] AASHTO = AASHTO M247 TY1; PA Spec = Penn M247 TY-1; VA Spec = Virginia M247 TY-1; Swarco = Swarco Megalux M247; Flex = Flex-O-Lite M247 TY1.
[b] 10 = 10 lb./100 sft; 6 = 6 lb./100sft; Flood = No quantity measurement taken.
[c] MP = Moisture-Proof Coating.
[d] Avery Dennison thermoplastic pavement marking materials are now produced by Ennis.

The NTPEP findings show that favorable performance on concrete can be achieved by some thermoplastic formulations even under heavy traffic wear. To achieve good performance with these materials, particular attention must be paid to the manufacturer's recommended surface preparation, primer materials, and other application procedures.

NATIONWIDE USE ON CONCRETE

The results and recommendations of the Florida International study and NTPEP data do not necessarily reflect the views of researchers and state DOT personnel in other parts of the country. Other recent research studies have tended to exclude thermoplastic markings on concrete surfaces due to adhesion problems. The survey of state DOTs performed by TTI in 2002 showed rather modest support for the use of thermoplastic as a longline pavement marking material on concrete.

Table 4 indicates that while many agencies use thermoplastic pavement markings on concrete, very few recommend it as the top performing material, most often due to experiences with premature material de-bonding, similar to that which TxDOT has experienced.

Table 4. DOT Use of Thermoplastic on Concrete.

DOTs Using Material on Concrete		Percent of DOTs Recommending as Top Performer	Potential Problems on Concrete	Avg. Contracted Costs of Material (per ft not incl. removal)	Service Life of Material on Concrete (years)	Concrete Surface Preparation
No.	%					
7	37	16	Poor Adhesion, Too Expensive, Flakes Off	$0.45	1-5	Epoxy Primer

Note: Indicates responses from 19 state DOTs.

Thermoplastic is used on PCC pavements in 37 percent of the surveyed states, but is considered the best performing material by only 16 percent. **DOT personnel stressed that successful thermoplastic performance on concrete is strongly influenced by proper surface cleaning, moisture removal, and priming (if necessary) prior to installation.** Many agencies recommend the use of two-component epoxy primers prior to thermoplastic application on concrete. Some states also recommend methods other than spraying, such as extrusion, for best performance on concrete. Proponents of thermoplastic markings claim that it will last between three and five years on high-ADT concrete when installed properly. Both hydrocarbon and alkyd thermoplastics received equal recommendation from agencies. Many mentioned that they had discontinued the use of thermoplastic on PCC surfaces due to premature bonding failures.

SURFACE PREPARATION AND PRIMERS

Surface preparation may likely play the most important role in the durability performance of thermoplastic markings on concrete. A clean, dry concrete surface is absolutely critical for thermoplastic markings to achieve suitable durability. Special pavement heating devices are now available that are effective for removing pavement surface moisture and elevating the pavement surface temperature, allowing for better thermoplastic bonding.

Manufacturers recommend that PCC pavements and asphalt surfaces that are more than two years old, oxidized, and/or have exposed aggregate should be treated with a primer (*9*). Current TxDOT guidelines recommend using an acrylic primer or waterborne paint on all concrete and aged asphalt surfaces prior to placing thermoplastic. However, the 2002 state agency survey found that most agencies using thermoplastic on concrete recommend a properly cured two-part epoxy primer (5-10 minutes for full cure). In addition, The FHWA Roadway Delineations Practices Handbook recommends a one-year concrete curing period before installing thermoplastic markings on PCC surfaces (*2*). Regardless of the surface type, the following steps must be taken to avoid adhesion problems between thermoplastic and concrete pavement surfaces:

- Clean pavement surface using a mechanical broom or compressed air to ensure that the surface is free of dirt, dust, and other contaminants.
- Remove curing compounds and existing pavement markings that are poorly bonded or of an incompatible material.
- Ensure pavement is dry.
- Ensure pavement and air temperatures are above 50ºF and 55ºF, respectively.
- Ensure that the thermoplastic temperature meets manufacturer specifications when it contacts the pavement.

SUMMARY OF THERMOPLASTIC FINDINGS

Based on the findings presented herein, thermoplastic pavement markings appear to be one of the most inconsistently performing pavement marking materials on concrete surfaces.

Some applications of thermoplastic materials perform very well on concrete, while others perform poorly. Additionally, some state DOTs have had great success with thermoplastic on concrete, while many others discourage its use on concrete.

The performance of a thermoplastic pavement marking on a concrete roadway surface is most often influenced by the quality of its bond to the pavement surface. It appears that for a given concrete roadway, the performance of the thermoplastic/concrete bond is highly linked to two factors:

- quality of surface preparation prior to application, including application of suitable primer (if the manufacturer recommends one) and
- thermoplastic material formulation.

Good performance of thermoplastic on concrete can often be traced to a well-prepared roadway surface and/or use of a more flexible and aggressive bonding thermoplastic material designed to withstand stresses induced by contraction/expansion of the concrete. High traffic volumes have a tendency to accelerate thermoplastic bonding problems on concrete, with markings becoming de-bonded as early as three months after application.

Table 5 presents recommendations made by TTI researchers pertaining to the use of thermoplastic pavement marking materials on concrete roadways.

Table 5. Recommended Use of Thermoplastic Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	**L**	**L**	**L**
Material Type	Specific Concrete Formulation[a] (more flexible material with aggressive bond to concrete)	Specific Concrete Formulation[a] (more flexible material with aggressive bond to concrete)	Specific Concrete Formulation (more flexible material with aggressive bond to concrete)
Thickness	60-90 mils	60-90 mils	60-90 mils
Surface Prep.	Clean, Dry & Epoxy Primer (refer to manufacturer recommendations)	Clean, Dry & Epoxy Primer (refer to manufacturer recommendations)	Clean, Dry & Epoxy Primer (refer to manufacturer recommendations)
Expected Service Life	Up to 4 years	Up to 4 years	Up to 4 years

Legend: **L** = Limited Use
[a] TxDOT specification thermoplastic (DMS 8220) may be used for applications with a life expectancy of two years or less.

CHAPTER 3:
EPOXY

Epoxy paints (also referred to simply as epoxy) are a two-component thermosetting material originally developed by Minnesota Department of Transportation in conjunction with H.B. Fuller and Company in the early 1970s. Epoxy paint has since developed into a common pavement marking alternative used by many agencies (*2*).

The first component of the epoxy typically contains resin, pigment, extenders, fillers, and glass beads. The second component acts as a catalyst to accelerate setting time. The ratio of the resin to the catalyst typically is in the range of 1:1 to 5:1. The setting time of epoxy paint is dependent on several factors, including the selection of the catalyst and the pavement temperatures at the time of application. Some slow-curing epoxies can take in excess of 40 minutes to dry. Fast curing epoxies that dry in as little as 30 seconds are available, but they are typically more expensive and often experience shorter service lives than their slow-cure counterparts. Typically, epoxy paints are applied to a film thickness of 10-20 mils (0.25-0.5 mm).

PERFORMANCE ON CONCRETE

Epoxy paint offers the advantages of being a durable, sprayable material that provides exceptional adhesion to both asphalt and Portland cement concrete pavements, while providing good resistance to abrasion. This exceptional durability is a result of tight bonding to the pavement surface that results from the chemical reaction that occurs when the two components are mixed. TxDOT currently has limited experience with epoxy pavement markings, but while epoxies have seen limited use in Texas, they have been included in many nationwide evaluations.

Research has shown that epoxy paints are generally less sensitive to application factors than thermoplastic materials, which allows for exceptional durability on a number of different roadway conditions (*2*). Epoxies can be applied at surface temperatures as low as 35ºF and when pavement surfaces are slightly wet. On low to mid traffic-volume roadways, epoxies have been known to provide service lives in excess of five years. Epoxies require proper cleaning of the pavement surface to achieve the best bond. Application of a primer material is not necessary on any roadway surface.

One of the more commonly reported problems with epoxy markings is color instability. Many epoxy materials have been known to fade under intense ultraviolet exposure. Some agencies also reported bonding problems due to inadequate surface preparation or moisture on the pavement surface. A usual complaint with many epoxy materials is the excessive drying time. Drying times in excess of 40 minutes are not uncommon for some epoxy materials, limiting the ability to stripe such materials under high traffic conditions. Quicker drying epoxies are available, which dry in less than two minutes, although these materials are often more expensive. Epoxies are also incompatible with most other pavement marking materials, limiting their usefulness in restripe conditions.

In the summer of 1984, the New York Department of Transportation tested the durability and retroreflectivity of over 1100 miles of epoxy pavement markings in 16 locations that were striped between 1978 and 1984 (*10*). The DOT included both asphalt and concrete roads in the evaluation, and markings were rated based on percent of the marking remaining and retroreflectivity. While the epoxies performed equally well in terms of percent remaining on concrete vs. asphalt surfaces, epoxies were found to provide much better retroreflective performance on concrete surfaces vs. asphalt.

Recent NTPEP testing has also shown favorable results for some epoxy materials on concrete. As described in Chapter 1, TTI research staff rated each of the NTPEP thermoplastic materials as "*good*," "*marginal*," or "*poor*" based on a combination of the retroreflectivity and durability performance on concrete pavements at the end of the second year. Table 6 displays the top performing epoxy materials from the recent NTPEP reports reviewed by TTI.

Table 6. Top Performing Epoxy Materials on Concrete Pavements (NTPEP).

Manufacturer	Product Number	NTPEP Location	Thickness (mil)	Primer/ Sealer	Bead Type[a]	Bead App. Rate[b]	Bead Coating
IPS	HPS-2	Penn.	14-22	None	Swarco	6	Silane
Sherwin-Williams	BP 17301	Penn.	20	None	AASHTO	Flood	Silicone

Notes: Information based on 2001-2002 NTPEP Deck Data.
NTPEP does not provide endorsement to any of the products listed in this table.
[a] AASHTO = AASHTO M247 TY1; PA Spec = Penn M247 TY-1; VA Spec = Virginia M247 TY-1; Swarco = Swarco Megalux M247; Flex = Flex-O-Lite M247 TY1.
[b] 10 = 10 lb./100 sft; 6 = 6 lb./100 sft; Flood = No quantity measurement taken.

NATIONWIDE USE ON CONCRETE

The survey of state DOTs performed by TTI in 2002 showed that **more state agencies currently use epoxy on high-ADT PCC surfaces than any other pavement marking material.** Table 7 displays state agency use of epoxy pavement marking materials on concrete.

Table 7. DOT Use of Epoxy on Concrete.

DOTs Using Material on Concrete		Percent of DOTs Recommending as Top Performer	Potential Problems on Concrete	Avg. Contracted Costs of Material (per ft not incl. removal)	Service Life of Material on High ADT Concrete (years)	Concrete Surface Preparation
No.	%					
13	68	16	Color Instability Under Intense Ultraviolet Radiation, Low Durability In Weaving Areas,	$0.39	3-5	Clean Surface, Remove Mkgs

Note: Indicates responses from 19 state DOTs.

It is interesting to note that while more than two-thirds of the responding DOTs use epoxy on concrete, only 16 percent recommend epoxy as the top performer on concrete (equal to that of thermoplastic), often favoring preformed tapes for utmost performance. This is often due to the slow drying times and color instability experienced with some epoxies.

SUMMARY OF EPOXY FINDINGS

Many types of epoxies exist. The information presented here, however, pertains only to high quality, high durability epoxy pavement marking formulations. Such epoxy materials provide exceptional durability on all roadway surfaces.

Based on the findings presented herein, epoxy pavement markings appear to be a suitable pavement marking material for concrete roadways. However, due to the excessive drying times, color stability issues, contractor inexperience, and inaccessibility of striping equipment, epoxies are currently not recommended for use on asphalt roadways, including sealcoats, in Texas.

It appears that for a given concrete roadway, the performance of an epoxy material is highly linked to three factors:

- quality of surface preparation prior to application,

- color stability under intense ultraviolet exposure, and
- ability to provide proper curing time for the markings prior to traffic exposure.

Table 8 presents recommendations made by TTI researchers pertaining to the use of epoxy pavement marking materials on concrete.

Table 8. Recommended Use of Epoxy Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	✔	✔	✔
Thickness	15-25 mils	15-25 mils	15-25 mils
Surface Prep.	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry
Expected Service Life	Up to 4 years	Up to 4 years	Up to 4 years

Legend: ✔ = Suitable for Use

CHAPTER 4:
PERMANENT PREFORMED TAPE

Preformed tapes are manufactured by melting and extruding plastic into the desired shape in the factory and are cold-applied in the field using either an overlay or an inlay installation procedure. Most tapes come with pre-applied adhesive protected by paper backing and are applied by removing the paper backing and pressing the tape to the pavement with either a roller or a truck tire.

PERFORMANCE ON CONCRETE

Tape is the most sensitive pavement marking material to place, maintaining some of the most stringent placement requirements. It is very important that the road is clean, dry, and the specified pavement and/or air temperatures have been reached. If the requirements for any of these factors have not been met, the tape may not achieve a strong enough bond with the pavement. Some tapes require pavement temperatures as high as 70ºF for overlay applications. Some specifications even require minimum air temperatures for the night before placement. Some of the disadvantages to using tape include the stringent application requirements and high initial cost. When applied correctly, preformed tapes can provide many advantages, including:

- long service life (four to eight years),
- initial retroreflectivity values that are four to six times better than traffic paint, and
- strong bond formation to both asphalt and PCC pavements.

Many agencies have evaluated preformed permanent tape in durable pavement marking studies. Some studies noted a dramatic drop in retroreflectivity over time, despite good to excellent durability (*11*,*12*), thereby suggesting use in heavy traffic urban areas with continuous roadway lighting. Tape pavement marking suppliers have recently developed tape products that claim to have better wet nighttime retroreflectivity values, although no independent studies on wet reflective pavement marking tapes were found in the literature.

Recent NTPEP testing has also shown very favorable results for some preformed tape materials on concrete. As described in Chapter 1, TTI research staff rated each of the NTPEP thermoplastic materials as "*good,*" "*marginal,*" or "*poor*" based on a combination of the retroreflectivity and durability performance on concrete pavements at the end of the second year.

Table 9 displays the top performing permanent preformed tape materials from the recent NTPEP reports reviewed by TTI.

Table 9. Top Performing Permanent Tape Materials on Concrete Pavements (NTPEP).

Manufacturer	Product Number	NTPEP Location	Thickness (mil)	Primer/ Sealer	Bead Type	Bead App. Rate	Bead Coating
3M	Stamark - 820	Penn.	-	P-50	Preapplied	-	-
		Cal.	-	N/A	Preapplied	-	-
3M	Stamark - 380	Penn.	-	P-50	Preapplied	-	-

Notes: Information based on 2001-2002 NTPEP Deck Data.
NTPEP does not provide endorsement of any of the products listed in this table.

NATIONWIDE USE ON CONCRETE

The survey of state DOTs performed by TTI in 2002 showed that **permanent preformed tapes were most frequently recommended as providing the best long term performance**. Table 10 displays state agency use of permanent preformed tapes as pavement marking materials on concrete.

Table 10. DOT Use of Permanent Tape on Concrete.

DOTs Using Material on Concrete		Percent of DOTs Recommending as Top Performer	Potential Problems on Concrete	Avg. Contracted Costs of Material (per ft not incl. removal)	Service Life of Material on High ADT Concrete (years)	Concrete Surface Preparation
No.	%					
12	63	58	Moisture Sensitive, Strict Temp. Req., Loss of Retro	$2.45	4-8	Clean Surf., Overlay with Adhesive, Remove Mkgs.

Note: Indicates responses from 19 state DOTs.

Preformed tape has been used by nearly two-thirds of the agencies surveyed, second only to epoxy. Most of the preformed tape use is in urban areas on high-traffic roadways and is often limited to short sections of roadway. Problems encountered with this material by some state agencies include: insufficient bonding, color fading, and inability to maintain high retroreflectivity over the service life of the marking. While preformed tapes often display the longest service lives of any material on the market, they are extremely expensive and time-consuming to install compared to most other materials.

SUMMARY OF PERMANENT PREFORMED TAPE FINDINGS

When properly installed, preformed tapes provide unmatched durability on concrete roadways surfaces. Based on the findings presented herein, preformed tapes are a suitable pavement marking material for concrete roadways, but consideration should be given to the cost of the material and the remaining service life of the pavement surface. Preformed tapes are highly recommended for use in urban areas with high traffic volumes.

It appears that for a given concrete roadway, the performance of a preformed tape material is highly linked to four factors:

- air and pavement surface temperature and surface moisture during application,
- quality of surface preparation prior to application,
- quality of adhesives, and
- ability to provide proper curing time for the adhesives prior to traffic exposure.

Table 11 presents recommendations made by TTI researchers pertaining to the use of permanent preformed tape pavement marking materials on concrete.

Table 11. Recommended Use of Permanent Tape Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	✖	✔	✔
Surface Prep.		Remove Existing Markings, Clean, Dry & Adhesive	Remove Existing Markings, Clean, Dry & Adhesive
Expected Service Life		Up to 6 years	Up to 6 years

Legend: ✔ = Suitable for Use, ✖ = Not Recommended

CHAPTER 5:
POLYUREA

Polyurea is a two-component, 100 percent solid thermosetting material that has been used as a multi-purpose coating material since 1989. Polyurea has outperformed traditional paints and epoxy coatings in highly abrasive environments on railcars, and is considered one of the most durable products available for truck bed liners.

Limited but rapidly increasing experience is currently available for polyurea pavement markings. Manufacturers market polyurea as a durable marking material with the following attributes:

- maintains good color stability when exposed to ultraviolet light,
- dries to no-track in three to eight minutes at all temperatures,
- may be applied at ambient pavement surface temperatures as low as 40ºF,
- is not affected by humidity; and
- provides excellent adhesion on both PCC and bituminous surfaces.

In addition, certain manufacturers give the option of including high-profile ceramic elements in their polyurea pavement markings to enhance retroreflectivity, especially under wet conditions.

PERFORMANCE ON CONCRETE

TxDOT has limited experience with polyurea pavement markings. A test section of 15 mil polyurea with retroreflectivity-enhancing ceramic elements was installed on a concrete section of US 290 in Cypress, Texas (ADT = 97,000)[7]. Initially, the retroreflectivity averaged between 800 and 850 mcd/m^2/lux for the white markings. After two years, the retroreflectivity of these markings had dropped but was still acceptable, averaging between 240 and 410 mcd/m^2/lux. An estimated 75 percent of the ceramic elements were lost or sheared after two years, although retention of the TxDOT specification drop-on beads was good. The durability of the polyurea material was considered excellent after two years, as there were no portions of the

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[7] Miller, J.S. *Evaluation of 3M Polyurea Traffic Stripe Containing Ceramic Beads.* Unpublished Document. Texas Department of Transportation, 2000.

markings that had cracked or de-bonded. The authors noted during nighttime visual inspections that yellow edgelines had a slightly white and washed-out appearance.

NATIONWIDE USE ON CONCRETE

Polyurea has seen use by 37 percent of the surveyed states. Please note that all but one of these states cited very little experience with this material, as it is relatively new to the pavement marking market. Therefore, data pertaining to polyurea reported herein should be used with discretion. Table 12 displays state agency use of polyurea pavement marking materials on concrete.

Table 12. DOT Use of Polyurea on Concrete.

DOTs Using Material on Concrete		Percent of DOTs Recommending as Top Performer	Potential Problems on Concrete	Avg. Contracted Costs of Material (per ft not incl. removal)	Service Life of Material on High ADT Concrete (years)	Concrete Surface Preparation
No.	%					
7	37	0	-	$0.97	-	Clean Surf., Remove Mkgs.

Note: Indicates responses from 19 state DOTs.

Table 12 shows that no agency reported it to be a best long-term material, although the positive feedback received from agencies suggests that this may be due to the lack of experience with this material. Most states reported that as of yet, they had not encountered any problems with the polyurea, although the durability and abrasion resistance of the ceramic elements in the 3M polyurea product is questionable. One of the major drawbacks is that special equipment is often necessary to apply this material[8]. Contracted costs were higher than most other materials, ranging from $0.92 to $1.00 per linear foot. Michigan DOT reported about four years of service life for this product when used on concrete. Illinois DOT estimated polyurea service life at about two years, although this estimate was based on very limited experience with the material.

[8] The type of equipment for application of polyurea materials depends on the resin/catalyst mix ratio. Polyureas with a 2:1 mix ratio for resin/catalyst may be applied with standard epoxy equipment.

SUMMARY OF POLYUREA FINDINGS

Although limited data on polyurea pavement markings currently exist, it appears that they provide exceptional durability on all roadway surfaces. The performance of polyurea materials on concrete is often compared to that of epoxy, but with quicker drying times and better color stability under ultraviolet exposure. Current material application costs are relatively expensive but should decrease as more manufacturers enter polyurea products onto the market and application equipment becomes more readily available. Issues with the washed-out appearance of yellow markings at night and the durability of the ceramic elements still exist. Based on the findings presented herein, polyurea pavement markings appear to be a suitable pavement marking material for concrete roadways. Table 13 presents recommendations made by TTI researchers pertaining to the use of polyurea pavement marking materials on concrete.

Table 13. Recommended Use of Polyurea Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	✔	✔	✔
Thickness	15-25 mils	15-25 mils	15-25 mils
Surface Prep.	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry
Expected Service Life	Up to 5 years	Up to 5 years	Up to 5 years

Legend: ✔ = Suitable for Use

CHAPTER 6:
OTHER MATERIALS

In addition to the four primary marking materials for concrete described in the preceding chapters (thermoplastic, epoxy, preformed tape, and polyurea), the researchers identified several other materials that have the potential to provide acceptable performance on concrete roadways under some conditions. These materials include methyl methacrylate, modified urethane, waterborne paints, and ceramic buttons.

METHYL METHACRYLATE (MMA)

Methyl methacrylate pavement markings are another two-component pavement marking system. The first component consists of a methyl methacrylate monomer, pigments, fillers, glass beads, and silica. The second component consists of benzoyl peroxide dissolved in a plasticizer. The two components are mixed immediately before application to form the polymer methyl methacrylate pavement marking (*13*). The components are usually mixed at a 4:1 ratio, and the markings can be applied by spray or extrusion.

Performance on Concrete

Methyl methacrylate is an attractive pavement-marking alternative for use on concrete due to several factors, including:

- low-temperature application;
- resistance to oils, antifreeze, and other chemicals commonly found on the roadway; and
- good bonding to both PCC and asphalt surfaces.

Disadvantages to using methyl methacrylate include:

- very expensive;
- limited experience in the United States;
- slow no-track times (about 20 minutes); and
- specialized equipment needed for application.

Nationwide Use on Concrete

The use of MMA pavement markings in the United States is very limited, but eastern Europe has been using this type of pavement marking for years. Oregon was the only surveyed state that listed methyl methacrylate as a material used on PCC surfaces, although Alaska and California have used MMA on asphalt surfaces with excellent performance in heavy snowfall areas. On the California test section after one winter, 95 percent of the MMA markings remained, while only 50 percent of the thermoplastic and paint markings remained in the same area. Oregon has found that the MMA markings generally provide a service life of six to eight years and are applied at a cost of $2.00 - $3.00 per linear foot, depending on whether the markings are recessed and/or profiled.

Summary of Methyl Methacrylate Findings

Very little experience exists with methyl methacrylate in the United States. As a result, very little application equipment exists, leading to very high application costs for agencies wanting to use the material. MMA appears to be well suited for cold climates because it can be applied at such low temperatures and is very resistant to snowplow and chemical damage. TTI researchers were unable to find any use of the material in warm-weather climates.

Table 14 presents recommendations made by TTI researchers pertaining to the use of methyl methacrylate pavement marking materials on concrete.

Table 14. Recommended Use of Methyl Methacrylate Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	**L**	**L**	**L**
Thickness	40 mils	40 mils	40 mils
Surface Prep.	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry
Expected Service Life	Up to 5 years	Up to 5 years	Up to 5 years

Legend: **L** = Limited Use

MODIFIED URETHANE

Modified urethanes are a two-component durable marking material with similar performance characteristics to those of polyurea and epoxy. Modified urethanes are currently available from one manufacturer (Innovative Performance Systems) and have been used experimentally in three of the surveyed states (16 percent). As a result, there is limited DOT experience from which to draw for this material. Reported material costs are slightly more expensive than epoxy but less than polyurea. This product is marketed as being slightly more durable than epoxy but with much quicker cure times (2 minutes) and better ultraviolet color stability. This material can be sprayed from any standard epoxy truck. Table 15 displays state agency use of modified urethane pavement marking materials on concrete.

Table 15. DOT Use of Modified Urethane on Concrete.

DOTs Using Material on Concrete		Percent of DOTs Recommending as Top Performer	Potential Problems on Concrete	Avg. Contracted Costs of Material (per ft not incl. removal)	Service Life of Material on High ADT Concrete (years)	Concrete Surface Preparation
No.	%					
3	16	0	-	-	-	Remove Mkgs.

Note: Indicates responses from 19 state DOTs.

Because such little experience exists with modified urethane pavement marking materials, Texas should limit use to an experimental basis, although this material seems to have promise on concrete roadways. More data are needed before conclusive recommendations can be made. Table 16 presents recommendations made by TTI researchers pertaining to the use of modified urethane pavement marking materials on concrete.

Table 16. Recommended Use of Modified Urethane Pavement Markings on Concrete.

Criteria	Traffic Condition		
	Low Volume	**Med. Volume**	**High Volume**
Use	**L**	**L**	**L**
Thickness	Manufacturer Recommendations	Manufacturer Recommendations	Manufacturer Recommendations
Surface Prep.	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry	Remove Existing Markings, Clean & Dry
Expected Service Life	Up to 4 years	Up to 4 years	Up to 4 years

Legend: **L** = Limited Use

WATERBORNE PAINTS

Traffic paints are the most widely used and inexpensive marking material available. Paints generally provide equal performance on both concrete and asphalt surfaces. Compared to other marking materials, paints have the shortest service life (2–12 months, depending on traffic), wear off rapidly, and lose retroreflectivity quickly when exposed to high traffic volumes or snow-removal action. As such, paints are only recommended as a temporary marking on high ADT concrete roadways.

Water-based paints are environmentally friendly, are much easier to handle than solvent-based paints, and greatly decrease the safety hazards to workers. However, most water-based paints do not dry as quickly solvent-based paints, especially when applied under humid conditions. They also have a tendency to settle or gel when left in storage containers over extended periods of time.

Nationwide Use on Concrete

Paint was used by 26 percent of the surveyed states on their PCC surfaces, although no state agency recommended it as the top performing long-term material. Several agencies used paint as an interim marking until something more durable could be placed. Michigan and Missouri reported paint as the primary material for most state-maintained roadways, although use is based less on good performance and more on state policy. Table 17 displays state agency use of waterborne paint pavement marking materials on concrete.

Table 17. DOT Use of Waterborne Paint on Concrete.

DOTs Using Material on Concrete		Percent of DOTs Recommending as Top Performer	Potential Problems on Concrete	Avg. Contracted Costs of Material (per ft not incl. removal)	Service Life of Material on High ADT Concrete (years)	Concrete Surface Preparation
No.	%					
5	26	0	Flakes Off	$0.04	-	Clean Surf.

Note: Indicates responses from 19 state DOTs.

Summary of Waterborne Paint Findings

More historical experience exists nationwide with paint than any other pavement marking materials. With more durable products on the market, paint is not a suitable permanent marking material for high traffic volume concrete roadways, regardless of the inexpensive application cost. Significant advancement has taken place with waterborne paints over the past few years, with some paints showing much greater durability than paint formulations of years past. However, it is too early to determine whether or not these materials will be suitable for use on high volume concrete. Table 18 presents recommendations made by TTI researchers pertaining to the use of waterborne paint pavement marking materials on concrete.

Table 18. Recommended Use of Waterborne Paint Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	✔	**L**	✖
Thickness	15-25 mils	15-25 mils	
Surface Prep.	Clean & Dry	Clean & Dry	
Expected Service Life	Up to 1 year	Up to 1 year	

Legend: ✔ = Suitable for Use, **L** = Limited Use, ✖ = Not Recommended

CERAMIC BUTTONS

TxDOT has used ceramic buttons extensively over the years. Until the recent change to TxDOT policy, which strongly discouraged the use of buttons, they were the third most often used pavement marking material in Texas behind thermoplastic and paint. While buttons often last for at least two years under the heaviest traffic conditions on concrete, the major complaint against their use is the lack of retroreflectivity provided by the materials, rendering them nearly invisible under headlamp conditions on unlit roadways. While RRPMs are used with buttons to supplement the lack of retroreflectivity, RRPMs generally have short service lives, making for poor nighttime visibility conditions when the RRPMs fail. Buttons do provide a tactile and audible sensation when driven over, similar to that of rumble strips, which may be considered a safety benefit.

Nationwide Use on Concrete

Only non-snowplow states use ceramic buttons for obvious reasons. California and Louisiana were the only two states in the survey to report the use of ceramic buttons on PCC surfaces, with neither recommending buttons as the top performer on concrete surfaces. The trend to move away from the use of buttons is not unique to TxDOT, however, as California indicated that they are also moving away from the use of buttons because of the tendency for them to become dirty quickly.

Summary of Ceramic Button Findings

Ceramic buttons are very different in appearance and application from all other marking materials. If used, they must be supplemented by RRPMs to provide nighttime visibility. Due to the fact that they are a non-retroreflective material, they are somewhat unpopular as a pavement marking material. The availability of application equipment and labor, especially in Texas, makes them an attractive material choice, although they are comparatively expensive. Table 19 presents recommendations made by TTI researchers pertaining to the use of ceramic button pavement markings on concrete.

Table 19. Recommended Use of Ceramic Button Pavement Markings on Concrete.

Criteria	**Traffic Condition**		
	Low Volume	**Med. Volume**	**High Volume**
Use	**L**	**L**	**L**
Surface Prep.	Clean, Dry & Epoxy Adhesive	Clean, Dry & Epoxy Adhesive	Clean, Dry & Epoxy Adhesive
Expected Service Life	Up to 5 years	Up to 4 years	Up to 3 years

Legend: **L** = Limited Use

CHAPTER 7:
VISIBILITY ENHANCING PAVEMENT MARKINGS

A recent nationwide roadway safety initiative has been established encouraging transportation agencies to provide pavement markings that are visible at all times of the day under all weather conditions. As a result, alternative pavement marking application procedures that enhance the visibility of markings are becoming increasingly popular nationwide. While retroreflective-raised pavement markers have historically been the most popular means of providing enhanced wet-night visibility, they are not described here. Two of the most popular visibility-enhancing pavement marking applications described here are profiled pavement markings and contrast pavement markings.

PROFILED PAVEMENT MARKINGS

Profiled pavement markings have recently become popular in southern non-snowplow regions as a means of providing visibility under wet conditions at night. Profiled pavement markings are most often constructed using thermoplastic, which will be described here. It should be noted that profiled markings are not necessarily limited to thermoplastic materials. Profiled markings may be constructed from materials other than thermoplastic as long as the same visual/tactile benefit is provided.

Profiled thermoplastic markings are sprayed or extruded thermoplastic markings that are constructed with an alternating elevated/recessed profile. The purpose of the profiled pattern is to provide nighttime retroreflectivity under wet conditions, and in cases where the profiles are large enough, drivers can feel a rumble effect when driving over the markings. The elevation/recession pattern may be placed using one of many methods. The two most popular methods are as follows:

- Inverted profile markings are created by a cog rolling over fresh wet thermoplastic, giving the line a corrugated appearance.
- Raised profile markings are created by extruding a thermoplastic marking of normal thickness with a raised thermoplastic “bump” (approx. 300 mil) at uniform spacing (often 3 ft).

Profiled thermoplastic generally performs well on all types of pavement surfaces, including concrete. These markings often cost significantly more than standard thermoplastic (up to six times the cost of standard materials) but are often warranted by the contractor. The good performance may be attributed to the stringent contractor-supplied on-site inspection that is provided during most applications.

CONTRAST PAVEMENT MARKINGS

Human vision is tuned to detect edges of contrasting color or brightness. Many concrete and heavily oxidized asphalt pavements are so light in color that during the day white pavement markings appear to blend in with the pavement surface. To improve the visibility of pavement markings on light-colored pavements during the day, markings are often being applied over the top of a compatible black marking material.

The underlying contrast material is often applied at a greater width than the actual marking so that it provides a contrasting border (minimum 1 inch) around the marking. Other applications include longitudinal leading or tailing sections of the black material of at least 12 inches in length. While contrast markings may be applied using most materials, material compatibility must be ensured since the actual marking is placed on top of the black marking.

Contrast markings are suitable for use on any concrete roadway surface where the daytime visibility of the pavement markings is poor due to a light-colored pavement surface. Because of the increased expense for application of contrast markings (often double the cost of standard markings of the same material), they are often only used for white lane lines on divided highways.

CHAPTER 8:
FINDINGS AND RECOMMENDATIONS

Approximately four percent of the centerline miles of highway on the TxDOT system are concrete pavements. However, these roadways carry approximately one-quarter of the vehicle-miles of travel on the highway system. Achieving acceptable pavement marking performance on these roadways can be a challenge, due to high traffic volumes and the de-bonding problems of some materials when applied to concrete. To help address the challenges associated with providing functional pavement markings on concrete, TTI researchers investigated the ability of various marking materials to provide acceptable durability and visibility when applied to concrete pavements. This report presents findings detailing the nationwide use and performance of numerous pavement marking materials and applications on concrete pavements.

This effort was prompted by the experiences of districts that were having difficulties getting the standard TxDOT thermoplastic marking material to provide adequate durability on concrete pavements. In some districts, thermoplastic markings have an expected life span of a year or less due to de-bonding between the marking and pavement surface.

ACTIVITIES

Researchers gathered information about various marking materials through five tasks: a review of the literature, a review of NTPEP evaluation data, a survey of selected state DOTs, a survey of the pavement marking industry, and a cost-effectiveness assessment of the various materials. The materials evaluated in these tasks included thermoplastic, epoxy, preformed tape, polyurea, methyl methacrylate, modified urethane, waterborne paints, and ceramic buttons.

SUMMARY OF FINDINGS

Pavement marking de-bonding problems are not unique to TxDOT, with many other DOTs reporting similar failures. While the material de-bonding issue on concrete is often associated with thermoplastic materials, other materials have been found to experience similar performance. This includes such highly recommended concrete-marking materials as epoxy and permanent tape. Researchers have determined that all materials are susceptible to premature bonding failures on concrete if the surface is not properly prepared and/or materials are not applied properly. Therefore, for any pavement marking material, the most important step to achieving acceptable bond performance on concrete is to follow the proper surface preparation and material application procedures as specified by the material manufacturer.

The survey of state agencies has shown that some pavement marking materials are clearly favored more than others for use on concrete roadways. However, these materials are often more expensive than standard materials, such as paint and thermoplastic, and therefore should only be used where needed. Figure 4 details the current use of pavement marking materials for longlines on concrete roadways by 19 state DOTs (not including TxDOT).

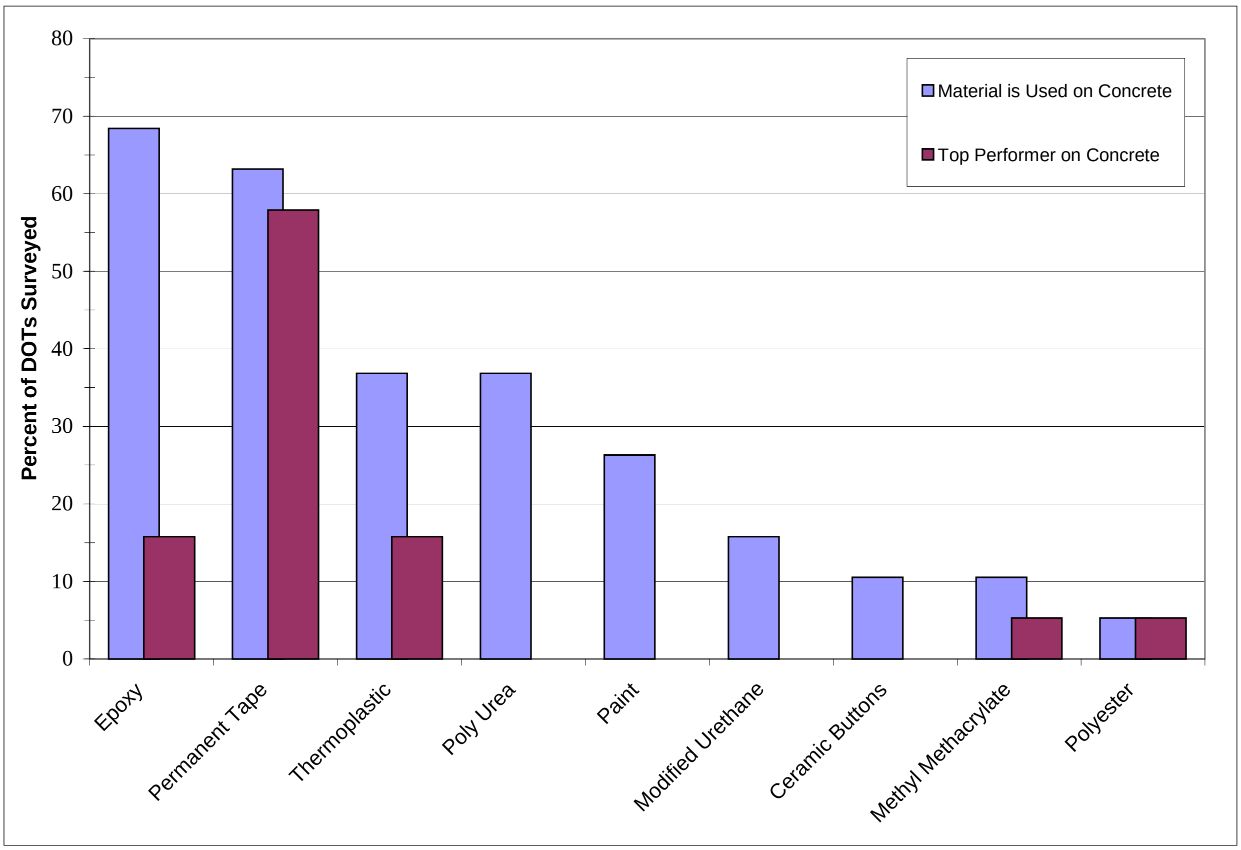

Figure 4. Summary of Findings from Survey of State DOTs.

Figure 4 shows that while epoxy was the most widely used pavement marking material on concrete roadways, a majority of agencies recommended permanent tapes as the top performing material on concrete under the most severe traffic conditions. Table 20 summarizes some of the key findings for the performance of each of the marking materials on concrete pavements. Table 21 summarizes the advantages and disadvantages of these same materials as determined from the research tasks. More detailed information about these materials can be found in the preceding chapters.

Table 20. Comparison of Marking Material Performance on Concrete Pavements.

Marking Material	Chapter	Contracted Material Cost Relative to TxDOT Spec. Thermo	Total Cost per Year of Service Life ($/LF/yr) [a]	Typical Service Life (years)	Surface Preparation	Lane Closure?
TxDOT Thermoplastic[b]	2	1X	0.33	2	Blast Clean[d], Primer Is Necessary	N
Concrete Thermoplastic[c]	2	1.75X	Unknown	Unknown	Blast Clean[d], Primer May Be Necessary	N
Epoxy	3	2X	0.22	4	Blast Clean[d]	Y
Preformed Tape	4	13X	0.76	4	Full Removal	Y
Polyurea	5	5X	0.37	4	Blast Clean[d]	N
Methyl Methacrylate	6	13X	Unknown	Unknown	Blast Clean[d]	Y
Modified Urethane	6	3X	Unknown	Unknown	Blast Clean[d]	N
Waterborne Paints	6	0.5X	0.19	1	Blast Clean[d]	N
Ceramic Buttons	6	3X	0.19	3	Full Removal	Y

Notes: [a] Includes: material cost, surface prep. cost, and removal cost for all materials (except removal cost is not included for paint)

[b] Current TxDOT thermoplastic marking. Average statewide cost for TxDOT thermoplastic as of Sept. 2002 is $0.20 per linear foot (12-month average for construction contracts).

[c] Thermoplastic formulated specifically for concrete pavements (not the same as the current TxDOT thermoplastic material).

[d] Full removal of existing markings is required if markings are de-bonding from the pavement, if the restripe and existing materials are not compatible, or if the marking profile is too thick.

Table 21. Summary of Attributes for Marking Materials on Concrete Pavements.

Marking Material	Advantages	Disadvantages
TxDOT Thermoplastic[a]	Low initial cost; availability of materials and contractors	May not bond well to concrete without suitable primer/sealer
Concrete Thermoplastic[b]	Improved durability on concrete vs. standard TxDOT thermoplastic	Slightly more expensive than TxDOT standard thermoplastic; relatively little use in Texas
Epoxy	Very good durability on concrete	Slightly more expensive than TxDOT standard thermoplastic; some epoxies are susceptible to fading under intense sunlight
Preformed Tape	Superior durability on concrete; most tape products are warranted by manufacturer	High initial cost; strict application requirements
Polyurea	Very good durability on concrete	Moderately high initial cost; may require specialized equipment to apply (depends on resin/catalyst ratio)
Methyl Methacrylate	Good durability on concrete; may be applied at cold temperatures	Very little use nationwide
Modified Urethane	Very good durability on concrete; may be placed with standard epoxy equipment	Very little use nationwide
Waterborne Paints	Very low initial cost	Short service life
Ceramic Buttons	Good durability on concrete; availability of materials and contractors	Provide no retroreflectivity

Notes: [a] Current TxDOT thermoplastic marking material.
[b] Thermoplastic formulated specifically for concrete pavements (not the same as the current TxDOT thermoplastic material).

RECOMMENDATIONS

Researchers developed recommendations made within this report based on sound judgment resulting from synthesis of information obtained from the various information-gathering tasks. Synthesis of information from these sources is important because it combines stakeholder knowledge and experience with objective data, allowing for well-founded recommendations to be made. Table 22 presents research-based recommendations for pavement-marking materials placed on concrete roadway surfaces as a function of traffic and remaining service life of the pavement. Table 23 presents commercially available pavement-marking materials that are suitable for use on concrete roadways surfaces as alternatives to the recommended materials listed in Table 22.

Table 22. Recommended Pavement Marking Materials for Concrete Pavements.

Traffic Characteristic[a]	Pavement Remaining Service Life		
	0-2 Years	2-4 Years	> 4 Years
AADT < 10,000	TxDOT Thermo[b]	Epoxy	Epoxy
10,000 < AADT < 50,000	TxDOT Thermo[b]	Epoxy	Epoxy
AADT > 50,000	Epoxy	Epoxy	Preformed Tape
Commercial Vehicles or Heavy Weaving/Turning	Epoxy	Preformed Tape	Preformed Tape

Notes: Contrast markings or profiled markings may be used to improve visibility and safety as needed.
[a] AADT = Average Annual Daily Traffic.
[b] Primer/sealer required prior to application of current TxDOT spec. thermoplastic on bare concrete.

Table 23. Alternative Pavement Marking Materials for Concrete Pavements.

Traffic Characteristic[a]	Pavement Remaining Service Life		
	0-2 Years	2-4 Years	> 4 Years
AADT < 10,000	Epoxy, Water-Based Paint	Thermo[b] (concrete formulation), Modified Urethane, Water-Based Paint, Polyurea, MMA	Thermo[b] (concrete formulation), Modified Urethane, Polyurea, Water-Based Paint, MMA
10,000 < AADT < 50,000	Epoxy, Modified Urethane, Water-Based Paint	Thermo[b] (concrete formulation), Modified Urethane, Polyurea, Water-Based Paint, MMA	Thermo[b] (concrete formulation), Preformed Tape, Polyurea, Modified Urethane, MMA
AADT >50,000	Thermo[b] (concrete formulation), Modified Urethane, Polyurea	Thermo[b] (concrete formulation), Preformed Tape, Polyurea, Modified Urethane, MMA	Epoxy, Thermo[b] (concrete formulation), Polyurea, Modified Urethane, MMA
Commercial Vehicles or Heavy Weaving/Turning	Thermo[b] (concrete formulation), Modified Urethane, Polyurea	Epoxy, Thermo[b] (concrete formulation), Polyurea, Modified Urethane, MMA	Epoxy, Thermo[b] (concrete formulation), Polyurea, Modified Urethane, MMA

Notes: Marking materials listed in order of recommendation, with the highest alternative recommendation listed first.
See Table 22 for the primary recommendations for marking materials on concrete pavements.
Contrast markings or profiled markings may be used to improve visibility and safety as needed.
[a] AADT = Average Annual Daily Traffic.
[b] Please see manufacturer's recommendations for use of primer/sealer prior to thermoplastic application.

In general, the findings and recommendations of this research effort indicate that TxDOT should not continue to use the current TxDOT thermoplastic marking material on concrete pavements unless significant changes are made in both surface preparation techniques and in the material specification to make it more compatible with concrete pavements. Thermoplastic pavement markings are arguably the most inconsistently performing pavement marking material on concrete surfaces across the country. Some applications perform exceptionally well, while others are complete failures. Some state DOTs have had great success with thermoplastic on concrete, while many others discourage its use on concrete.

It does appear, however, that the quality of the concrete surface preparation (including primer application if necessary) greatly influences the quality of the thermoplastic adhesion with the concrete. Good performance of thermoplastic on concrete can often be traced to a well-prepared roadway surface and/or use of a more flexible thermoplastic material specially designed for use on concrete. Although thermoplastic materials are by far the most popular pavement marking material in Texas, they should only be used on concrete roadways with great discretion, with particular attention given to preparation of the roadway surface.

Epoxies[9], preformed tapes, and other two-component materials have shown consistently good performance on concrete pavements across the country and are recommended by numerous sources. Permanent preformed tape appears to provide the longest service life for high traffic-volume concrete roadways, although it has a very high material and application cost. TxDOT should conduct additional experimentations with epoxy and other two-component materials on concrete pavements to assess installation and performance over a period of time on high traffic-volume concrete roadways. Epoxy marking materials may provide the most economical replacement for thermoplastic if the degradation caused by exposure to ultraviolet light proves to be an insignificant issue in Texas.

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[9] Many epoxy formulations exist. The recommendations made herein apply only to high quality, high durability epoxy materials that are commercially available from established vendors for use as pavement markings.

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5. *First Year Field Performance & Laboratory Test Results of Pavement Marking Materials, 2000 Pennsylvania Test Deck.* Report 02 – NTPEP 221. National Transportation Product Evaluation Program, American Association of State Highway and Transportation Officials, Washington, D.C., February 2002.

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APPENDIX A: NTPEP PAVEMENT MARKING FIELD TESTING PROCEDURES

A major resource for comprehensive pavement marking evaluations performed at the national level is the National Transportation Product Evaluation Program (NTPEP). NTPEP is responsible for testing and evaluating products, materials, and devices that are commonly used by the American Association of State Highway and Transportation Officials (AASHTO) Member Departments of Transportation (DOTs). NTPEP evaluations of pavement marking materials are usually performed both in field and laboratory environments, with an emphasis on field performance of materials. Manufacturers voluntarily submit products for testing by NTPEP. NTPEP evaluations culminate in a formal report that is written by the state DOT in which the field evaluation was performed and is published and distributed by AASHTO. Test data are furnished within the report; however, per NTPEP/AASHTO policy, no approval, disapproval, or endorsements of products are made.

TTI researchers obtained and reviewed the following three recent NTPEP pavement marking reports:

- 2000 Urban California Test Deck (first year data), Report 02 NTPEP 216 (*i*);
- 2000 Pennsylvania Test Deck (first year data) [1], Report 02 NTPEP 221 (*ii*); and
- 1999 Mississippi Test Deck (second year data), Report 02 NTPEP 220 (*iii*).

Each of the three reports was obtained because the evaluations included the most up-to-date pavement marking materials on concrete roadway surfaces. The California report was of particular interest due to the high traffic volumes through the test sections. Table A1 displays a summary of the characteristics of each site.

[1] Unpublished second-year data were received by TTI from PennDOT and were used for material evaluation.

Table A1. NTPEP Site Characteristics.

Criteria		2000 Urban California	2000 Pennsylvania	1999 Mississippi
Location	Concrete	US 50 (WB[a]), Sacramento	I-80 (EB[b]), Williamsport	US 78 (WB[a]), New Albany
	Asphalt	US 50 (WB[a]), Sacramento	I-80 (WB[a]), Williamsport	US 78 (EB[b]), Tupelo
ADT	Concrete	160,000	10,000	20,000
	Asphalt	160,000	10,000	15,000
Material Installation Date		August 2000	July 2000	July 1999
Snowplowing?		No	Yes	No
Total Number of Materials Evaluated		33	180	100
Material Types		Thermo, Preformed Thermo, Permanent Tape, Polyurea, Modified Urethane	Paint, Thermo, Preformed Thermo, Permanent Tape, Removable Tape, Epoxy, Polyurea, Modified Urethane, Methyl Methacrylate, Experimental Products	Paint, Thermo, Preformed Thermo, Permanent Tape, Removable Tape, Epoxy

[a] WB = westbound
[b] EB = eastbound

FIELD PROCEDURES

In each evaluation, NTPEP field testing was performed according to the procedures developed by the NTPEP Subcommittee for Pavement Marking Materials, which are based on ASTM Specification D 713-90 "Conducting Road Service Tests on Traffic Paint" (*iv*). In each evaluation, all pavement marking materials were installed on both the bituminous asphalt surface and the Portland cement concrete surface. The material manufacturers, under the supervision of the lead agency, were responsible for placement of their respective striping materials. Multiple beaded transverse lines were placed for each material sample. Lines extended across the right lane from the left side of the right edgeline to the left side of the lane line. Primers/sealers were used with selected thermoplastic and tape materials.

In each case, the marking materials were evaluated based on the field testing procedures described in ASTM D 713-90 (*iv*). The lead agency for each evaluation performed all field data collection. Field data were initially collected within the first few days after application. Subsequent data collection was performed at monthly intervals for the first year after application and at quarterly intervals during the second year[2]. The following field data were collected for each material sample during each data collection event:

- subjective rating of the durability and appearance,
- quantitative retroreflectivity measurement (30-meter geometry), and
- quantitative color measurement[3].

Subjective ratings of durability were made with a team of trained evaluators. Retroreflectivity measurements were made using a portable handheld retroreflectometer with 30-meter geometry. Durability and retroreflectivity measurements were obtained in two locations for each transverse sample line:

- within the 18-inch left wheel path area to approximate maximum wear conditions and
- within the 9-inch area at the lane line to approximate normal wear conditions.

Material durability was determined by estimating the percentage of the stripe remaining (non-exposed substrate) at each of the two locations on the line. Durability ratings were assigned by taking 10 percent of the percentage remaining (e.g., 60 percent remaining equals a durability rating of 6). Durability ratings were therefore reported on an integral scale from 0 to 10.

REFERENCES - APPENDIX A

i. *2000 NTPEP Pavement Marking Field Performance History & Lab Test Results on Select Products, 2000 Urban California Test Deck.* Report 02 - NTPEP 216. National Transportation Product Evaluation Program, American Association of State Highway and Transportation Officials, Washington, D.C., October 2001.

ii. *First Year Field Performance & Laboratory Test Results of Pavement Marking Materials, 2000 Pennsylvania Test Deck.* Report 02 – NTPEP 221. National Transportation Product Evaluation Program, American Association of State Highway and Transportation Officials, Washington, D.C., February 2002.

iii. *Second Year and Final Report of Field Performance Evaluation of Pavement Marking Materials, 1999 Mississippi Test Deck.* Report 02 – NTPEP 220. National

[2] The California and Pennsylvania reports include first-year data only, as second-year data have not yet been reported. The Mississippi report includes only second-year data.
[3] Color measurements were not necessarily performed during every data collection event.

Transportation Product Evaluation Program, American Association of State Highway and Transportation Officials, Washington, D.C., February 2002.

iv. *Standard Practice for Conducting Road Service Tests on Fluid Traffic Marking Materials.* ASTM D 713-90 (1998). ASTM International, West Conshohocken, Pennsylvania, 1998.

APPENDIX B:
STATE AGENCY SURVEY

Note: Survey was emailed to 19 state DOT personnel in mid-June 2002. Answers were obtained via telephone conversations with DOT personnel.

<u>DOT Pavement Marking Practices for High Volume Concrete Surfaces</u>

1. What types of durable pavement marking materials does your agency regularly use on **high-volume concrete freeways** (ADT > 100,000)?

   Please include:
   - approximate service life
   - approximate contracted cost per foot
   - surface preparation

2. Of the materials listed in Question 1, which provide the best long-term performance?

3. Have you had performance/durability problems on concrete surfaces with any of the materials in Question 1?

4. How does your agency deal with the 14-day MUTCD requirement for placement of permanent markings on a new roadway surface if the intended permanent markings cannot be placed within that time frame?

APPENDIX C:
INDUSTRY SURVEY

Note: Survey was emailed to 14 industry contacts in mid-June 2002.

Pavement Marking Materials for High Volume Concrete Surfaces

1. What specific types of durable pavement marking materials does your company recommend for use as long lines on **high-volume concrete** roadway surfaces (average daily traffic > 100,000 vehicles) if the material is to remain retroreflective and adhere to the roadway for **4 years**?

   Please include:

   Product ID numbers or name
   Material cost (per ton for liquid markings; per foot for tape)
   Approximate contracted application cost per foot
   Recommended thickness
   Range of ambient air temperatures for application
   Approximate no-track drying time
   Recommended surface preparation
   Recommended primer/sealer (if any)

2. If you listed more than one material in Question 1, which would you recommend for **best overall performance** if the material **must stay on the road for at least 4 years**?

3. In the hot and humid Gulf Coast region of Texas, high-volume traffic conditions require that most concrete striping be performed at night. Under these conditions, ambient air temperatures may range from 40-90°F with 30-90 percent humidity. Moisture condensation on the roadway surface often occurs, as well. Given these conditions, would any of the materials recommended in Question 1 be adversely affected? Please explain.

4. Do you have any other suggestions for how TxDOT can provide long life markings on very high-volume concrete roadways?