An Investigation into Application and Bonding Strengths of Thermoplastic Pavement Markings on Concrete and Asphaltic Roadway Surfaces

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Executive Summary

AN INVESTIGATION INTO APPLICATION AND BONDING STRENGTHS OF THERMOPLASTIC PAVEMENT MARKINGS ON CONCRETE AND ASPHALTIC ROADWAY SURFACES

Thermoplastic pavement markings are known to have poor adhesion on concrete surfaces. They were observed to have failed within six to eight months. The markings appear to hold better on asphalt surfaces. The purpose of this investigation was to compare bonding strengths of thermoplastic markings on concrete and asphalt surfaces. Another related but additional objective was to determine the effectiveness of various surface preparation techniques.

The research study was carried out in two distinct phases. First, information on the topic was gathered through an extensive literature search. The hypothesis of this investigation, that thermoplastic has poorer bonding on concrete than on asphalt surfaces, was substantiated by the results of this search. As a part of this effort the investigators contacted department of transportation (DOT) offices of the states of Georgia, Texas, Louisiana and California. The specifications of these four states regarding application of thermoplastic stripes were obtained. These states also encounter problems with thermoplastic markings in one form or other. In general, tape markings are preferred over thermoplastic markings. In the second stage, experimental investigation was conducted. A test site with asphalt and concrete surfaces was selected to perform the adhesion test. Four different surface preparation techniques were used on both type of surfaces. The techniques are: (1) Waterblasting, (2) Grinding/scarifying, (3) Sandblasting, and (4) Wire brushing. In addition test was also performed with no surface preparation at all to provide the control set of data. Adhesion test, according to ASTM D 4541-95, using standard apparatus was performed in order to obtain adhesion strength for each surface preparation technique. It was found that grinding/scarifying produced the best result on both asphalt and concrete surfaces. Sandblasting and wire brushing were found to be the least effective techniques on asphalt and concrete respectively. In general, the extent of improvement on concrete was found to be marginal when compared to the strength obtained for asphalt based on the no-treatment value. Although grinding/scarifying was found to be the most effective on both asphalt and concrete surfaces, the value obtained with concrete was lower than the corresponding adhesion strength for asphalt despite the fact that the control value for concrete was higher than asphalt. The extent of improvement for asphalt was 161%, while the corresponding improvement for concrete was 108%.

As expected, surface treatment techniques, in general, were found not to be very effective on concrete. The researchers, however, recommend another thorough investigation of long term performance of thermoplastic markings on concrete under vehicular traffic. It should be emphasized that the concerns of many FDOT engineers regarding poor bonding of thermoplastic markings on concrete are validated by this investigation, although based on this limited study we do not recommend any change in the current specifications. We recommend use of the adhesion test but standards for its use have to be developed. Based on the findings, we recommend the use of grinding/scarifying as the most effective surface treatment technique. It should be noted that the scope of this project was limited to only comparing two types of pavement surfaces for a short period of time. Two important variables - long term performance and performance under actual vehicular traffic were not studied in this investigation. Despite this limitation the investigators feel that the findings of this investigation added significant value to the existing body of knowledge on this topic and can be useful for developing future research programs.

AN INVESTIGATION INTO APPLICATION AND BONDING STRENGTHS OF THERMOPLASTIC PAVEMENT MARKINGS ON CONCRETE AND ASPHALTIC ROADWAY SURFACES

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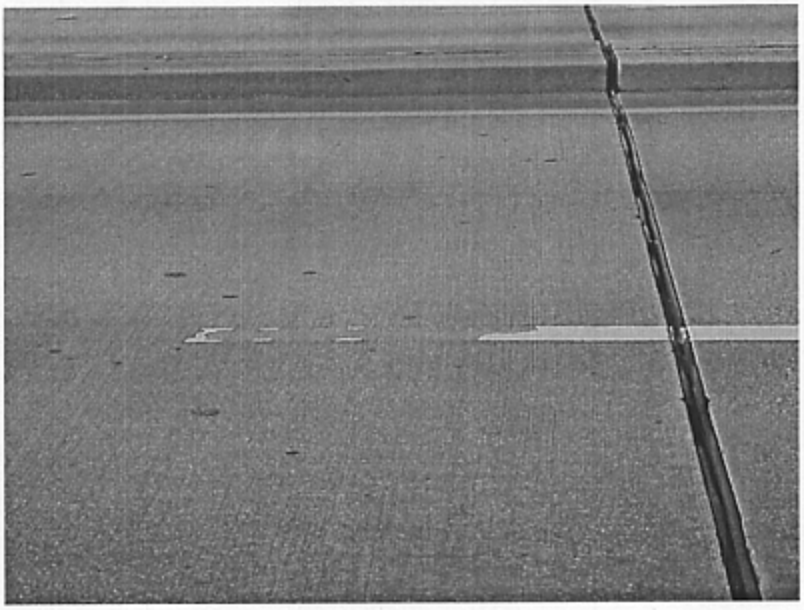
Chapter 1 - Introduction

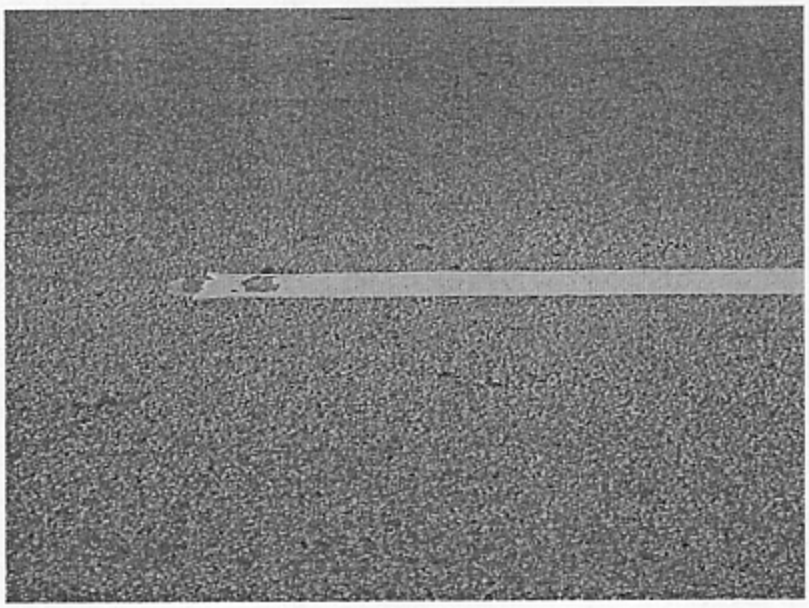
1.1 Problem Statement

Experience indicates that thermoplastic pavement markings fail on concrete surfaces within 6 to 8 months. (e.g. - Marrell Barber Bridge in Vero Beach). They loose their bond with the concrete and tend to flake off. The markings appear to hold better on asphalt surfaces. A comparison of the two is shown in Figure 1. The exact reason causing this problem has not been identified yet. But the poor markings caused by the lack of proper adhesion to concrete surfaces creates several problems. First of all, it is a safety concern - the motoring public is forced to travel a roadway with poorly defined center and edge lines which may lead to accidents. Secondly, it is costly the department's (FDOT) maintenance forces because failing thermoplastic markings must be replaced with paint within a short period of time. Finally, contract disputes may arise.

Despite these problems, thermoplastic markings are used on concrete pavements and bridge decks on a regular basis throughout the state of Florida. This research report is the result of an investigation undertaken to study several surface treatment methods, and to determine the appropriate conditions and proper methods of application of thermoplastic markings on roadway surfaces.



(a)



(b)

Figure 1. Comparison of thermoplastic markings on (a) concrete pavement and (b) asphalt pavement (Location: Coral Way and SW 117th Avenue, Miami, Florida).

1.2 Scope and Objectives

The objective of this research is to obtain answers to the following questions:

1. Are thermoplastics suitable for concrete surfaces?

It is possible that the required adhesion cannot develop between concrete surfaces and thermoplastics. No definitive information is currently available on this issue.

2. Is the application procedure sound?

If the material is usable on concrete surfaces, the correct technique and procedure for surface preparation and application should be determined and followed.

In order to obtain answers to the research questions posed above, the researchers undertook and completed the following tasks:

Literature Review and Survey of Current Practices

A survey was conducted to find out the extent of use of thermoplastic markings on concrete pavement surfaces and bridge decks in the state of Florida and a few southern states with similar weather patterns - including Georgia, Texas, Louisiana and California. Information was gathered on the specifications, durability and usual methods of application on both concrete and asphaltic roadway surfaces.

Develop and Test Surface Preparation Models

This task was central to this research project and, as such, took the major portion of the project time. It was divided into the following subtasks:

A. Select test site - With the help of Mr. Jim Lynch, Resident Engineer, FDOT office in

Ft. Pierce, the research team selected portions of substrate (both concrete and asphaltic) for conducting physical tests involving the application of thermoplastic markings. FDOT also coordinated participation of a contractor in this effort and provided MOT (maintenance of traffic) during the testing phase.

B. Surface preparation models - Four variable surface preparation models and one control model were tested on actual roadway surfaces for both concrete and asphaltic substrates. The models were:

Model 1:	Water-blasting prior to thermoplastic application
Model 2:	Grinding/scarifying prior to thermoplastic application
Model 3:	Sandblasting prior to thermoplastic application
Model 4:	Wire brushing prior to thermoplastic application
Model 5 (Control)	No surface preparation prior to thermoplastic application

In addition, another model consisting of the application of a new thermoplastic marking over an existing one was tested on the asphaltic roadway surface only.

C. Apply thermoplastic markings - With the help of FDOT personnel and the participating contractor, thermoplastic markings were applied according to the FDOT specifications and manufacturers' recommendations on the prepared surface models as described in *B* above.

D. Gather material data and conduct physical response field testing - The chemistry lab (State Materials Office in Gainesville) conducted laboratory material tests on the thermoplastic material used for this project. These results provided the investigators with the following information:

Miscellaneous laboratory test results on the thermoplastic material, including

Lead content

Titanium dioxide content (white material) (ASTM D 1394)

Softening Point (ASTM D 36)

Color (ASTM D4960)

Glass Bead Content (AASHTO T250)

Glass Sphere Gradation (ASTM D1214)

Sphere Roundness (ASTM D 1155)

Index of Refraction (AASHTO M 247).

In addition to the above, the State Materials Office (Contact: Joyline L. Benham, Project Manager of this project) conducted physical response field testing including:

1. Fifteen and thirty meter retroreflectivity testing, FM 5-541.
2. Striping thickness determination, FM 5-541.
3. Site conditions at application.

E. Conduct field tests - After allowing at least 24 hours, as per manufacturers' specifications, for the required bonding strength between the thermoplastic material and the substrate surface to develop, adhesion tests were to be conducted on all of the applied thermoplastic markings under investigation. This test, known as the *adhesion test* or *pull-off test* (ASTM D4541), was performed by the investigators. The chemistry lab of the State Materials Office (SMO) provided the adhesion tester to the investigators.

Analyze results

Test results were compiled and the results obtained were analyzed. The differences

between the two types of surfaces (concrete and asphaltic) were highlighted. Conclusions and recommendations regarding the application procedure were made and other relevant information was documented.

1.3 Organization of the Report

In this chapter, the scope and the objectives of the research project are outlined. The problem is defined and the research questions are laid out.

The remainder of the report is organized as follows:

In Chapter 2, results of the literature search are reported. Findings of literature survey on the use of thermoplastic markings and experiences of other states on their use and performance are included in this chapter. Next, results of adhesion tests corresponding to different surface preparation models are described in details in Chapter 3. Results of retroreflectivity test and other material tests are also included in this chapter. Analysis and interpretation of the results are presented in Chapter 4. Lessons learned are discussed and suggestions for further study are included in Chapter 5. In the last chapter (Chapter 6), conclusions of the study are highlighted and recommendations for future actions by FDOT and potential researchers are outlined.

Chapter 2 - Literature Review and Survey of Current Practices

2.1 Literature Survey

The investigators conducted an extensive literature survey on the use of thermoplastic markings on pavement surfaces. The list of articles found includes:

1. Attaway, R. W. (1989). "In-Service Evaluation of Thermoplastic and Tape Pavement Markings Using a Portable Retroreflectometer," *Work-zone traffic control and tests of delineation material*, Transportation research record 1230, National Research Council, Washington, D.C.

In this article the author introduces the use of portable retroreflectometers to evaluate the reflectivityof longitudinal markings. Two hand-held retroreflectometers (Ecolux and Mirolux 12) were used. Retroreflectometers measure reflectivity of pavement markings through manual placement on a small section of pavement marking.

2. Chollar, B.H, and Appleman, B.R. (1980). *Epoxy Thermoplastic Pavement Marking Material:*

Specification and Testing. Report No. FHWA/RD-80/069, Federal Highway Administration, Offices of Research and Development, Materials Division, HRS-20, Washington, D.C.

This report presents the results of an extensive laboratory program to establish a specification for an epoxy thermoplastic striping material. Properties studied included viscosity, reflectance, thermal stability, softening point, epoxy equivalent weight, and infrared spectrum. Analytical procedures for determining the titanium dioxide, lead chromate, glass bead, and organic contents were also incorporated into the specification.

3. Niessner, C.W. (1984). *Field Evaluation of a Generic Thermoplastic Pavement Marking Material*. Report No. FHWA-TS-83-201, Federal Highway Administration, Office of Implementation, HRT-10, Virginia.

This is the most relevant of all publications, the investigators considered related to this study. In this research work, a generic formulation of a hydrocarbon-based thermoplastic was tested in New York, Oklahoma, and Virginia. Stripping was placed on both bituminous (asphaltic) and portland cement concrete pavements in all three states. Overall, the performance of the thermoplastic primer systems was found to be very good except for the portland cement test section in New York. This section was considered marginal in terms of delineation value. On asphalt pavement surfaces, stripes performed equally well on both epoxy and linseed oil primers, as well as on bare pavement. On concrete pavement surfaces, stripes placed over the epoxy primer performed better than those over linseed oil. The tests were conducted during 1979-80. Thermoplastics and pavements have both changed dramatically since then. One of the observations made in the paper relates closely to the topic of this study. The observation was, "Adhesion was markedly better on asphalt pavement than on concrete pavement." As a probable cause the weaker initial bond formed on concrete was mentioned.

4. ASTM - American Society for Testing and Materials, *Standard Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*, Designation: D4541-85.

This test method was used to obtain the pull-off strength of thermoplastic coatings in this research. It covers a procedure and apparatus for evaluating the pull-off strength (commonly referred to as adhesion) of a coating by determining either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive coating system, and substrate and will be exposed by the fracture surface. This method uses a class of apparatus known as pull-off adhesion testers. They are portable and capable of applying a concentric load and counter load to a single surface so that coatings can be tested even though only one side is accessible. The ASTM standard method is provided in the Appendix A.

2.2 Survey of Current Practices

Specifications from the state departments of transportation were obtained. The states of Georgia, Texas, Louisiana and California were contacted for specifications.

Georgia - Georgia DOT has reviewed and tested permanent tape in various small experimental sections and in the laboratory. The cost analysis was done to compare the life cycle cost difference between tape and thermoplastic usage. Based on a six-year life span for the tape in various experimental stations, the comparison showed the tape to be more cost effective. In recent studies conducted by the Georgia DOT, it was found that tape markings were more effective than thermoplastics.

Texas - Texas DOT specifications cover materials, composition, quality, sampling, and

testing of thermoplastic materials. Thermoplastic pavement marking material is allowed to be used on either asphaltic or Portland cement concrete surfaces. Material requirement in terms of pigments, prime pigments, filler pigments, binder, and silica are specified. In addition, manufacture, contaminants and gradation of glass traffic beads are also specifed.

California - Thermoplastic material and glass beads used shall conform to state specifications set up by Transportation Laboratory in California. The surface that is to receive the thermoplastic material shall be mechanically wire brushed or abrasive blasted to remove the dirt, contaminants, and curing compound. Thermoplastic paints shall be applied only to dry pavement surfaces and only when the pavement surface temperature is above 10 °C.

Louisiana - The specification covers hot-sprayed or hot-extruded reflective thermoplastic compound for pavement markings on asphaltic or concrete pavement. Description of material, surface preparation, suitability for application, and color are included in the specifications.

The specifications of these four states (Georgia, Texas, California and Louisiana) regarding applications of thermoplastic stripes are included in the Appendix B.

In addition to the above, the following research materials were obtained by the investigators:

Interdepartment Correspondence on Selection of Type PB Permanent Tape for Use on Concrete Surfaces, Department of Transportation, Georgia. This document (Appendix C) includes as attachements the following published materials:

- Thermoplastic versus Permanent Tape Cost Comparison Contrast Markings on Concrete Pavements MAU (maintenance activities unit) 1995.

- Thermoplastic versus Tape Cost Comparison GDOT Lab 1995.
- Don Wishon E-mail on Lab Cost Comparison.
- Pennsylvania NTPEP Test Deck Values on Concrete Report 98-NTPEP 142.
- Texas NTPEP Test Deck Values on Concrete Report 98-NTPEP141.

2.3 Summary

Other states, as investigated in this study, also encountered problems with thermoplastic markings. In general, tape markings are preferred over thermoplastic markings. It was also evidenced that thermoplastic markings are less effective on concrete than asphaltic surfaces.

Chapter 3 - Adhesion and other test results

3.1 General

This test was conducted according to the ASTM (American Society for Testing and Materials) designation: D 4541-95 entitled Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers (See Figure 2). The method covers a procedure for evaluating the pull-off strength or adhesion of a coating by determining either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). In this research project, the investigators attempted to determine the perpendicular tensile force required to detach the coating material from the base surface. The ASTM D 4541-95 test procedure and description are provided in the Appendix A.

The following are selected excerpts from the ASTM publication:

"This test method uses a class of apparatus known as portable pull-off adhesion testers. They are capable of applying a concentric load and counter load to a single surface so that coatings can be tested even though only one side is accessible. Measurements are limited by the

strength of adhesion bonds between the loading fixture and the specimen surface or the cohesive strengths of the adhesive, coating layers, and substrate.

Figure 2. Adhesion tester.

"The general pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detahced, or a specifed value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved."

3.2 Field-test models and protocol

The tasks involved in developing and testing surface preparation models are as follows:

a. Select test site

b. Prepare surface models

c. Apply thermoplastic markings

d. Gather material data

e. Conduct adhesion test

According to the project plan, five surface preparation models were tested on both asphaltic and concrete pavement surfaces. Four variable surface preparation models and one control model, as listed below, were tested on actual roadway surfaces for both concrete and asphaltic substrates.

Model 1:	Waterblasting prior to thermoplastic application
Model 2:	Grinding/scarifying prior to thermoplastic application
Model 3:	Sandblasting prior to thermoplastic application

Model 4:	Wire brushing prior to thermoplastic application
Model 5 (Control)	No surface preparation prior to thermoplastic application

In addition, a different field condition consisting of applying thermoplastic markings over existing markings on asphalt pavement surface was also included.

The site was in Stuart, Florida, near the Turnpike toll plaza on State Road 714. The map of the location is shown in Figure 3. Mr. Jim Lynch, Resident Engineer of FDOT Ft. Pierce, arranged for a contractor to do the surface preparation as well as application of thermoplastic markings. FDOT also coordinated participation of the contractors in this effort and provided MOT (maintenance of traffic) during the preparation and testing phases.

The field testing portion of this study was conducted during the two days of October 13 and 14, 1999. Both concrete and asphaltic surfaces were prepared according to the models described above. With the help of FDOT and the participating contractor, thermoplastic markings were applied according to the FDOT specifications and manufacturers' recommendations on the prepared surface models as described above. Pertinent data, such as ambient temperature, surface temperature, thermoplastic temperature, relative humidity, thickness of the layers of thermoplastic strips were collected. Site conditions at application were also noted. Samples were also collected for subsequent laboratory tests as described and reported in Chapter 4.

All field tests were scheduled to be conducted the next day (Oct. 14, 1999). But due to inclement weather condition (related to Hurricane Irene), the project team decided to come back during the following week to conduct the field tests.

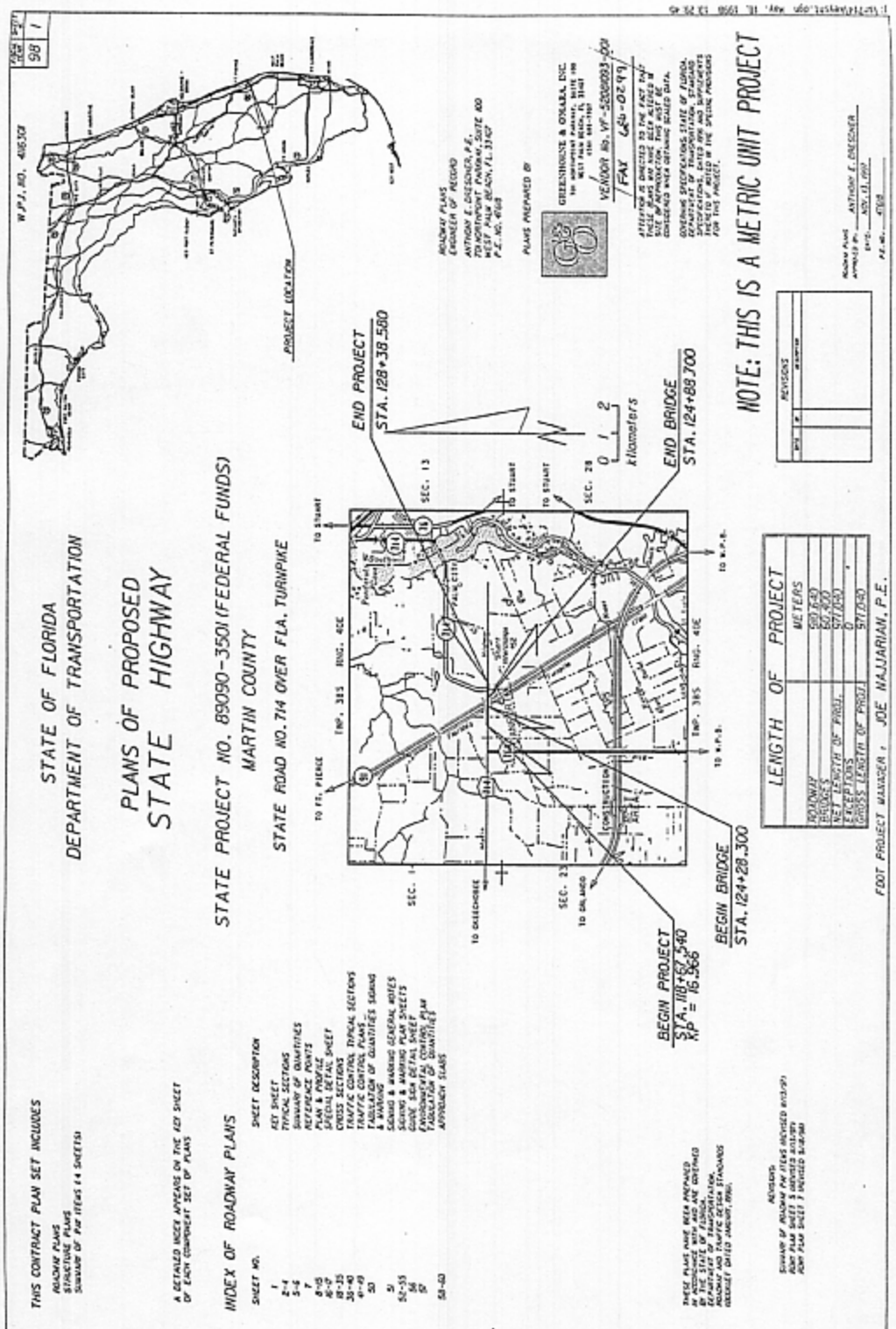


Figure 3. Map showing the location of the site where investigation was carried out.

3.3 Description of the procedure followed

As described in the ASTM D 4541 procedure (Appendix A), the procedure for the adhesion test calls for stainless steel dollies, as shown in Figure 4, to be placed on the thermoplastic coatings. The bottom surface of the dollies was attached to the thermoplastic coating with a light-blue colored epoxy glue (Figure 5). According to the specifications, at least 24 hours should be allowed before the pull-off test is done. The investigators had to wait seven days due to the inclement weather mentioned earlier.

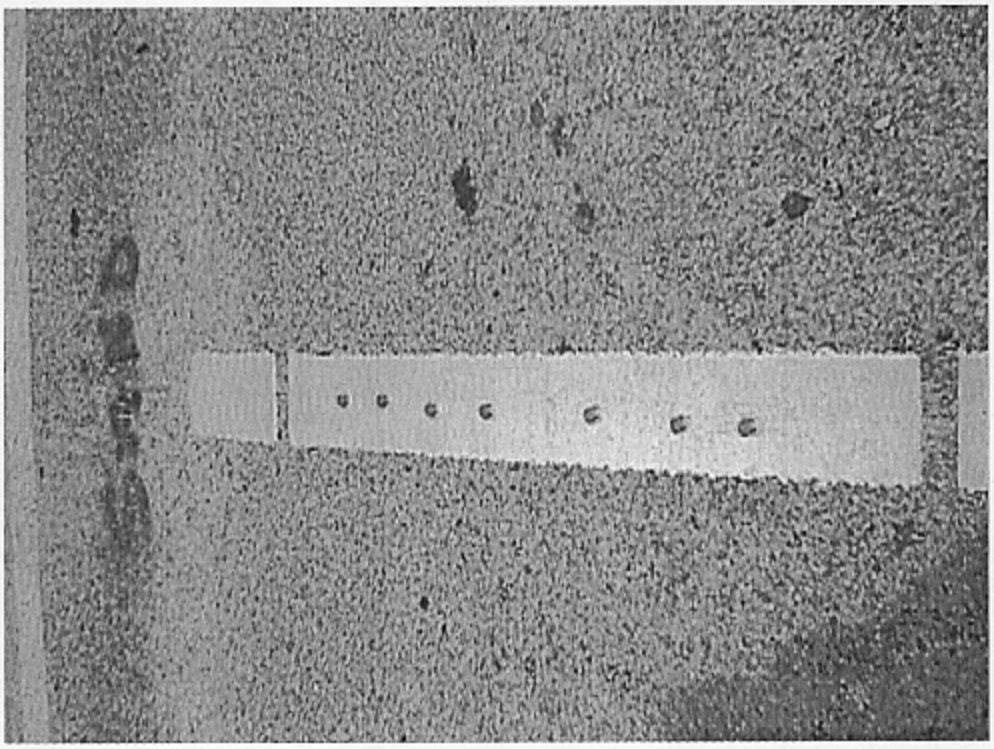


Figure 4. Stainless steel dollies in place before the Adhesion Test.

Figure 5. Epoxy glue being applied for dollies to be attached to thermoplastic markings.

3.3.1 Surface treatment models

As mentioned earlier, four surface treatment models and one control model (no surface treatment - regular cleaning with a blower) were investigated for both pavement types. These models, with relevant information, are listed below:

Water blasting - 36,000 to 40,000 psi compressed air pressure at 1 to 5 gallon per minute.
Grinding/scarifying - rotary blades, only enough pressure applied to remove debris without damaging asphalt.
Sandblasting - Sharp silicon, minimum 100 cu.ft/min, at 75 to 125 psi.
Wire brushing - manually conducted with commercially available wire brushes.

The techniques, as applied in this investigation, are shown in Figures 6, 7, 8 and 9.

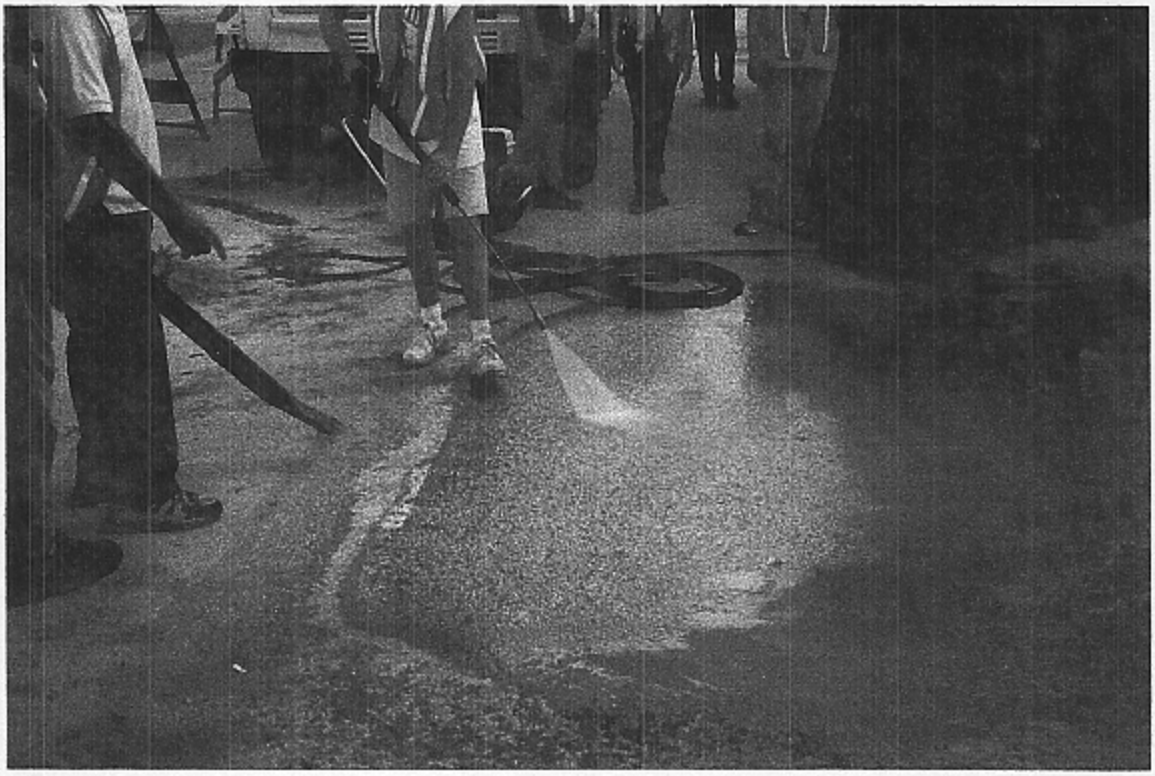


Figure 6. Water blasting.

Figure 7. Grinding/scarifying.

Figure 8. Sandblasting

Figure 9. Wire brushing

3.4 Adhesion test results

The results of the adhesion test are reported separately for asphaltic and concrete pavement surfaces in the following.

3.4.1 Asphalt pavement

Ideally, the pull-off test result should indicate the pressure needed to separate the thermoplastic coating from the pavement surface, as illustrated in Figure 10. However, failure or separation may also take place between the epoxy glue and thermoplastic coating, and in case of asphaltic pavement, the asphalt surface may fail under the pull before the bonding failure between the thermoplastic coating and asphalt surface. The bottom surface of some dollies after they were pulled out from asphalt and concrete stripes are shown in Figures 11 and 12, respectively. In addition to the expected mode of failure between thermoplastic coating and asphalt, the investigators also witnessed these two other types of failure as explained above and as reported in Table 1.

Both asphalt and epoxy failures may actually be indicative of the fact that the bonding between the thermoplastic and the asphalt is stronger than the measured pressure, although it could not be precisely known.

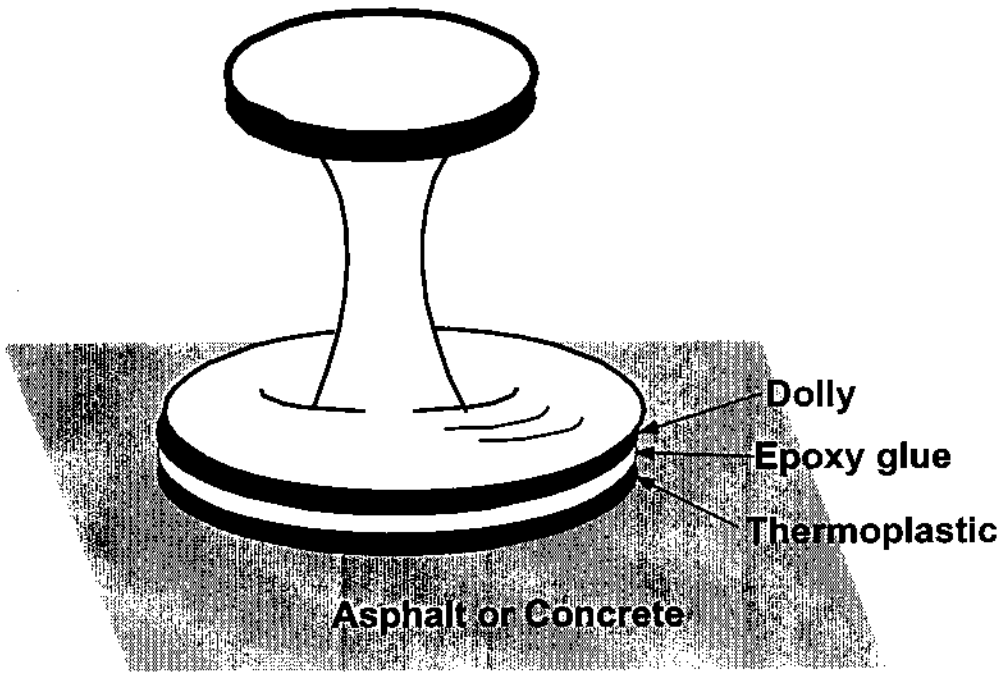


Figure 10. Adhesion surfaces under the test-dolly as placed on the pavement surface.

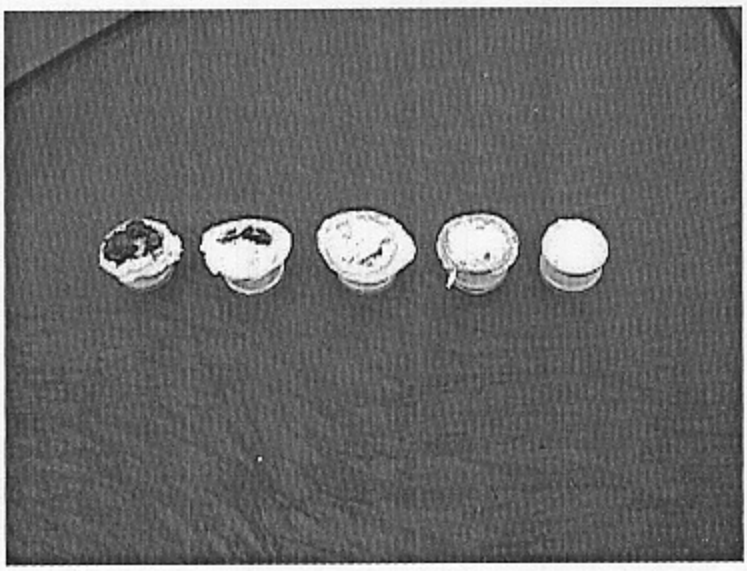


Figure 11. Bottom surface of dollies on asphalt after the test.

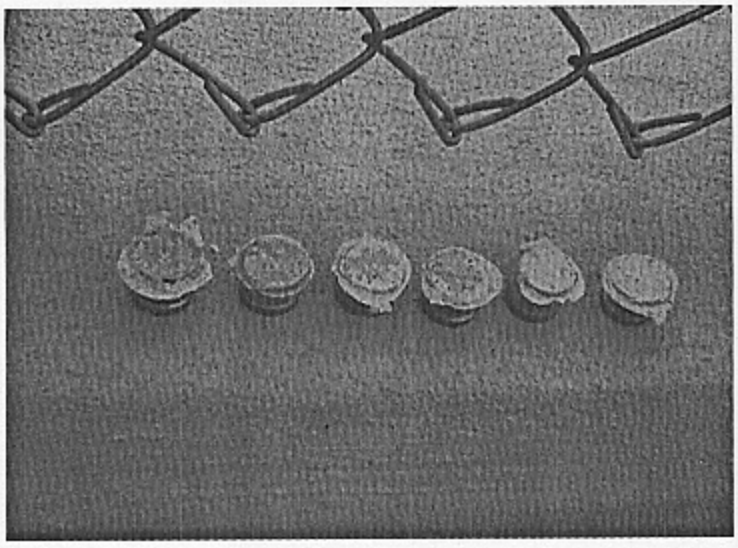


Figure 12. Bottom surface of dollies on concrete after the test.

Table 1. Asphalt pavement surface - adhesion stress in psi

Asphalt Surface treatment	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average
Control- no treatment	**150** thermopla stic failure	150 asphalt failed	150 Epoxy glue failed	145 Epoxy glue failed	100 Epoxy glue failed	125 Epoxy glue failed	**150**
Sand-blasting	**150** thermopla stic failed	**160** thermopla stic failed	**170** thermopla stic failed	n/a Asphalt failed	**160** thermopla stic failed	n/a	**160**
Wire brushing	**180** Thermopla stic failed	**200** Thermopla stic failed	140 Asphalt failed	185 Asphalt failed	**140** Thermopla stic failed	**180** Thermopla stic failed	**175**
Grinding/ Scarifying	**210** Thermopla stic failed	**220** Thermopla stic failed	**295** Thermopla stic failed	120 Asphalt failed	140 Asphalt failed	160 Asphalt failed	**242**
Water- blasting	**300** Thermopla stic failed	**200** Thermopla stic failed	**200** Thermopla stic failed	**160** Thermopla stic failed	**190** Thermopla stic failed	**170** Thermopla stic failed	**203**
Existing thermoplastic stripes	**110** New thermopla stic failed	**110** New thermopla stic failed	**140** New thermopla stic failed	95 Old coating failed	110 Old coating failed	n/a	**120**

3.4.2 Concrete pavement

As per specification, all concrete test strips were coated with epoxy primer before thermoplastic application, but after the surface treatment. This epoxy primer is known commercially as traffic sealer under the brand name of "sealcrete" having a boiling point of 104^{0}F, and a specific gravity of 1.01 (available from: Service Paint, 3048 Brandau Road, Hermitage, TN 37076) In the case of concrete, epoxy coating failure between thermoplastic and epoxy glue was observed in some cases as indicated in Table 2. The results are shown graphically in Fig. 13. As expected, no concrete pavement failure (concrete detaching from concrete due to adhesion test pressure) under the thermoplastic coating was observed.

Table 2. Concrete pavement surface - adhesion stress in psi

Concrete Surface treatment	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average
Control-no treatment	**180** thermopla stic failed	**200** thermopla stic failed	**200** thermopla stic failed	**150** thermopla stic failed	**220** thermopla stic failed	**250** thermopla stic failed	**200**
Sand-blasting	**170** thermopla stic failed	**185** thermopla stic failed	**240** thermopla stic failed	210 epoxy failed	260 epoxy failed	220 epoxy failed	**198**
Wire brushing	**210** Thermopla stic failed	**160** Thermopla stic failed	250 Epoxy failed	**140** Thermopla stic failed	**100** Thermopla stic failed	**195** Thermopla stic failed	**161**
Grinding/ Scarifying	**230** Thermopla stic failed	190 Epoxy failed	**250** Thermopla stic failed	**150** Thermopla stic failed	**270** Thermopla stic failed	**180** Thermopla stic failed	**216**
Water-blasting	**310** Thermopla stic failed	**200** Thermopla stic failed	**190** Thermopla stic failed	**185** Thermopla stic failed	**140** Thermopla stic failed	**100** Thermopla stic failed	**188**

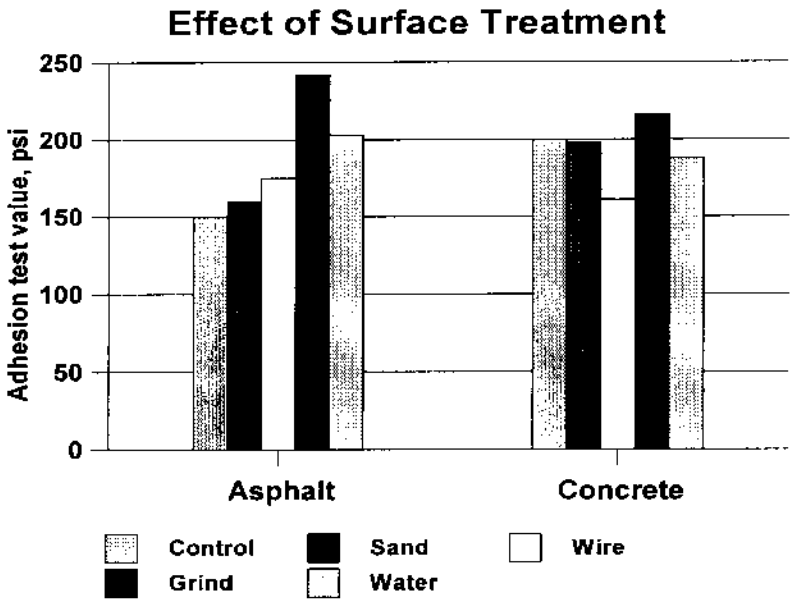


Figure 13. Graphical representation of adhesion test results

3.5 Other test results

Other tests included:

1. Fifteen and thirty meter retroreflectivity testing, FM 5-541 - Retroreflectivity of pavement (Road) markings degrades with traffic wear and requires periodic measurement to ensure sufficient visibility is provided to motorists. The purpose of including the retroreflectivity

test in this investigation was to properly identify the product being used, and to record the general parameters of the product properties.

2. Laboratory tests on the thermoplastic material.

Retroreflectivity results are shown in Table 3 and Table 4 for asphaltic and concrete surfaces respectively.

Table 3 (a) Thirty meter Retroreflectivity on asphalt

LTL 2000 (MCD/LUX/M2)	Measurement 1	Measurement 2	Measurement 3	AVERAGE	TEST RESULTS
1. Water-blasting	79	99	101	93	Failed
2. Grinding	242	213	196	223	Failed
3. Sandblasting	178	212	245	212	Failed
4. Wire brushing	257	271	264	264	Passed
5. No Surface Preparation	205	195	218	206	Failed
6.On top of existing thermoplastic	187	129	99	138	Failed

Table 3 (b) Fifteen meter Retroreflectivity on asphalt

MIROLUX 15 (MCD/LUX/M2)	Measurement 1	Measurement 2	Measurement 3	AVERAGE	TEST RESULTS
1. Waterblasting	173	193	173	180	Failed
2.Grinding	307	327	312	315	Passed
3. Sandblasting	349	314	324	329	Passed
4. Wire Brushing	382	362	351	365	Passed
5. No Surface	398	312	276	329	Passed
6.On top of existing thermoplastic	153	206	306	222	Failed

Table 4 (a) Thirty meter Retroreflectivity on concrete

LTL 2000 (MCD/LUX/M2)	Measurement 1	Measurement 2	Measurement 3	AVERAGE	TEST RESULTS
1. Water-blasting	214	184	164	187	Failed
2. Grinding	128	74	77	93	Failed
3. Sandblasting	122	118	132	124	Failed
4. Wirebrushing	197	200	189	195	Failed
5. No Surface Preparation	200	151	136	162	Failed

Table 4 (b) Fifteen meter Retroreflectivity on concrete

MIROLUX 15 (MCD/LUX/M2)	Measurement 1	Measurement 2	Measurement 3	AVERAGE	TEST RESULTS
1. Water-blasting	248	213	239	233	Failed
2.Grinding	294	276	240	270	Failed
3. Sandblasting	257	215	218	230	Failed
4. Wirebrushing	319	279	281	293	Failed
5. No Surface Preparation	274	258	194	242	Failed

Other test results, attached in Appendix D, include:

Site conditions at application

Glass sphere gradation

Glass bead content

Softening point

Color

Titanium dioxide (TiO_2) content

Index of refraction

Percent round

Chapter 4 - Analysis and interpretation of results

The main objective of this investigation was to determine the effectiveness of thermoplastic markings on concrete pavement surfaces as compared to asphaltic surfaces. In this chapter, major findings are enumerated.

4.1 Adhesion test results

It can be concluded from Table 1 that on asphaltic surfaces:

a. Grinding/scarifying produced the best results followed by water-blasting and wire-brushing techniques of surface treatment.

b. Sandblasting produced the poorest results.

c. Surface treatment, regardless of the type, was found to be somewhat effective.

From Table 2 we can conclude that on concrete surfaces:

a. Grinding/scarifying proved to be the best surface treatment technique. This was followed by sandblasting and water-blasting.

b. Wire-brushing was found to be the least effective.

c. Most treatment techniques, with the exception of grinding/scarifying, were found to be marginally or less effective as compared to the no-treatment value.

A comparison between the values tabulated in Tables 1 and 2 reveals that:

a. Although the grinding/scarifying technique was found to be the most effective on both asphalt and concrete surfaces, the value obtained with concrete is lower than the corresponding value for asphalt (242 for asphalt versus 216 for concrete), despite the fact that the control or no-treatment value for concrete was higher than asphalt (200 versus 150). In other words, the extent of improvement for asphalt was (242/150 =) 161%, while the corresponding improvement for concrete was (216/200 =) 108%.

b. All other techniques, with the exception of sandblasting, also proved that asphalt holds thermoplastic markings better than concrete.

4.2 Other test results

Both fifteen and thirty meter retroreflectivity tests on concrete indicate failure for all surface treatment techniques including no-treatment (control) condition.

On asphalt, all but the wire-brushing technique failed to achieve the specified value of the thirty meter retroreflectivity test. On the other hand, with the exception of the water-blasting

technique, all surface treatment techniques passed the specified value for the fifteen meter test on asphalt surface.

Field samples of white thermoplastic did not meet specification requirements for intermix glass sphere content. They were deficient by 2% by weight. Further, the glass spheres did not meet the specification requirements for Type I. Adhesion test results - the focus of this investigation - are not affected by retroreflectivity, although the material used in this study did not meet the retroreflectivity criteria,

Chapter 5 - Suggestions for further investigations

5.1 Lessons learned

The results of this research investigation, as detailed in Chapters 3 and 4, point out the obvious difference between the two pavement materials, asphalt and concrete, in regards to performance of thermoplastic markings. Thermoplastic markings on concrete do not perform as well as they do on asphalt. There may be a variety of reasons for this problem. But our investigation was focused on comparing the two pavement surfaces for different surface treatment techniques. While substantial improvement was observed on asphalt due to surface treatments, very little or no improvement was noticed on concrete. We do not recommend discontinuation of the use of thermoplastic markings on concrete based on this limited study. Further investigation should be carried out for more definitive answers regarding its use on concrete.

5.2 Suggestions for future research

Future research on this topic may take different directions based on the focus of study. In the following, a number of areas for future investigation are pointed out. Lessons learned from this project will serve well in formulating future research studies as outlined below.

5.2.1 Long term study

Adhesion of thermoplastic markings on concrete should be investigated over a period of one year. Most failure (flaking off) occurred within this time frame. We suggest that the adhesion test be carried out on the same test strip at the end of one, three, six, nine and twelve month periods.

5.2.2 Study performance under vehicular traffic

Performance of thermoplastic markings on both asphalt and concrete surfaces under vehicular traffic should be studied. When combined with the long term study this should provide definitive information about

5.2.3 Further investigation of surface treatment techniques

Two surface treatment techniques, **grinding/scarifying** and **water-blasting** were found to be very effective. We suggest that these two techniques be further studied in order to adopt them as a part of the standard guideline.

5.2.4 Test different products

In this study we have tested only one commercial product supplied by the contractor that failed in several respects as indicated by the laboratory tests. Other leading products should also be tested using a uniform research protocol before any definitive conclusions can be made on their performance.

Chapter 6 - Conclusions and Recommendations

6.1 Limitations of the study

Before summarizing the conclusions of the study and presenting its recommendations, we feel that it is very important that the limitations of this study are clearly pointed out. First of all, the scope of the project was limited to only comparing two types of pavement surface - asphalt and concrete for four different surface treatment techniques. Two important variables - long term performance and performance under actual vehicular traffic were not studied in this investigation.

Despite the limitations outlined above, we strongly feel that the findings of this investigation added significant value to the existing body of knowledge on this topic and can be useful for developing enhanced scopes of future investigations.

6.2 Conclusions

The major findings of this research study include:

- The observation that prompted this study, thermoplastic markings do not bond as well on concrete pavement as they do on asphalt, is substantiated by the results of the investigation.

- Grinding/scarifying was found to be the most effective technique of surface treatment on both concrete and asphaltic surfaces.
- Water-blasting and wire brushing techniques were found to be somewhat effective on asphalt pavement.
- Sandblasting was not as effective as the other techniques on asphalt.
- With the exception of grinding/scarifying, all surface treatment techniques were found to be ineffective on concrete.
- In general, the extent of improvement due to surface treatments was higher in asphalt than in concrete.

6.3 Recommendations

We recommend another thorough investigation of long term performance of thermoplastic markings on concrete under vehicular traffic. Surface treatment techniques, in general, were found not to be very effective on concrete. Based on this limited study, however, we do not recommend discontinuation of the use of thermoplastic markings on concrete, but we would like to emphasize that the concerns of FDOT engineers regarding poor bonding of thermoplastic markings on concrete are validated by this investigation. We recommend the use of grinding/scarifying as the most effective surface treatment technique on asphaltic pavement.

Bibliography

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3. Niessner, C.W. (1984). *Field Evaluation of a Generic Thermoplastic Pavement Marking Material*. Report No. FHWA-TS-83-201, Federal Highway Administration, Office of Implementation, HRT-10, Virginia.

4. ASTM - American Society for Testing and Materials, *Standard Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*, Designation: D4541-85.

Appendix-A ASTM Designation D4541-85

Designation: D 4541 – 95[ε1]

Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers[1]

This standard is issued under the fixed designation D 4541; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

[ε1] NOTE—Research report added editorially in August 1995.

1. Scope

1.1 This test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating by determining either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, coating system, and substrate, and will be exposed by the fracture surface. This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scratch or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon both material and instrumental parameters. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

1.2 This test method uses a class of apparatus known as portable pull-off adhesion testers.[2] They are capable of applying a concentric load and counter load to a single surface so that coatings can be tested even though only one side is accessible. Measurements are limited by the strength of adhesion bonds between the loading fixture and the specimen surface or the cohesive strengths of the adhesive, coating layers, and substrate.

1.3 This test can be destructive and spot repairs may be necessary.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding[3]

D 3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)[3]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[4]

2.2 *ANSI Standard:*

N 512 Protective Coatings (Paints) for the Nuclear Industry[5]

2.3 *ISO Standard:*

4624 Paints and Varnish—Pull-Off Test for Adhesion[5]

3. Summary of Test Method

3.1 The general pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Pull-off strength results obtained using different devices may be different because the results depend on instrumental parameters (see Appendix X1).

4. Significance and Use

4.1 The pull-off strength of a coating is an important performance property that has been used in specifications. This test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the results. This test method is applicable to any portable apparatus meeting the basic requirements for determining the pull-off strength of a coating.

4.2 Variations in results obtained using different devices

[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coating.

Current edition approved Feb. 15, 1995. Published April 1995. Originally published as D 4541 – 93. Last previous edition D 4541 – 93.

[2] The term adhesion tester may be somewhat of a misnomer, but its adoption by two manufacturers and at least two patents indicates continued usage.

[3] *Annual Book of ASTM Standards*, Vol 15.06.

[4] *Annual Book of ASTM Standards*, Vol 06.01.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

or different substrates with the same coating are possible (see Appendix X1). Therefore, it is recommended that the type of apparatus and the substrate be mutually agreed upon between the interested parties.

5. Apparatus

5.1 *Adhesion Tester,* commercially available, or comparable apparatus specific examples of which are listed in Annexes A1 to A4.

5.1.1 *Loading Fixtures,* having a flat surface on one end that can be adhered to the coating and a means of attachment to the tester on the other end.

5.1.2 *Detaching Assembly* (adhesion tester), having a central grip for engaging the fixture.

5.1.3 *Base,* on the detaching assembly, or an annular bearing ring if needed for uniformly pressing against the coating surface around the fixture either directly, or by way of an intermediate bearing ring. A means of aligning the base is needed so that the resultant force is normal to the surface.

5.1.4 Means of moving the grip away from the base in as smooth and continuous a manner as possible so that a torsion free, co-axial (opposing pull of the grip and push of the base along the same axis) force results between them.

5.1.5 *Timer,* or means of limiting the rate of stress to less than 150 psi/s (1 MPa/s) so that the maximum stress is obtained in less than about 100 s. A timer is the minimum equipment when used by the operator along with the force indicator in 5.1.6.

NOTE 1—Obtaining the maximum stress in 100 s or less by keeping the maximum rate of shear to less than 150 psi/s (1 MPa/s) is valid for the levels of pull-off strength measured with these types of apparatuses.

5.1.6 *Force Indicator and Calibration Information,* for determining the actual force delivered to the loading fixture.

5.2 *Solvent,* or other means for cleaning the loading fixture surface. Finger prints, moisture, and oxides tend to be the primary contaminants.

5.3 *Fine Sandpaper,* or other means of cleaning the coating that will not alter its integrity by chemical or solvent attack. If any light sanding is anticipated, choose only a very fine grade abrasive (400 grit or finer) that will not introduce flaws or leave a residue.

5.4 *Adhesive,* for securing the fixture to the coating that does not affect the coating properties. Two component epoxies[6] and acrylics[7] have been found to be the most versatile.

5.5 *Magnetic or Mechanical Clamps,* if needed, for holding the fixture in place while the adhesive cures.

5.6 *Cotton Swabs,* or other means for removing excess adhesive and defining the adhered area. Any method for removing excess adhesive that damages the surface, such as scoring, must generally be avoided since induced surface flaws may cause premature failure of the coating.

5.7 *Circular Hole Cutter* (optional), to score through to the substrate around the loading fixture.

6. Test Preparation

6.1 The method for selecting the coating sites to be prepared for testing depends upon the objectives of the test and agreements between the contracting parties. There are, however, a few physical restrictions imposed by the general method and apparatus. The following requirements apply to all sites:

6.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. The surface may have any orientation with reference to gravitational pull. Each test site must be separated by at least the distance needed to accommodate the detaching apparatus. The size of a test site is essentially that of the secured loading fixture. At least three replications are usually required in order to statistically characterize the test area.

6.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force. It should be noted that measurements close to an edge may not be representative of the coating as a whole.

6.2 Since the rigidity of the substrate affects pull-off strength results and is not a controllable test variable in field measurements, some knowledge of the substrate thickness and composition should be reported for subsequent analysis or laboratory comparisons. For example, steel substrate of less than ⅛-in. (3.2-mm) thickness usually reduce pull-off strength results compared to ¼-in. (6.4-mm) thick steel substrates.

6.3 Subject to the requirements of 6.1, select representative test areas and clean the surfaces in a manner that will not affect integrity of the coating or leave a residue. Surface abrasion may introduce flaws and should generally be avoided. A fine abrasive (see 5.3) should only be used if needed to remove loose or weakly adhered surface contaminants.

6.4 Clean the loading fixture surface as indicated by the apparatus manufacturer. Failures at the fixture-adhesive interface can often be avoided by treating the fixture surfaces in accordance with an appropriate ASTM standard practice for preparing metal surfaces for adhesive bonding.

NOTE 2—Guides D 2651 and D 3933 are typical of well-proven methods for improving adhesive bond strengths to metal surfaces.

6.5 Prepare the adhesive in accordance with the adhesive manufacturer's recommendations. Apply the adhesive to the fixture or the surface to be tested, or both, using a method recommended by the adhesive manufacturer. Be certain to apply the adhesive across the entire surface. Position fixture on the surface to be tested. Carefully remove the excess adhesive from around the fixture.

NOTE 3: **Caution**—Movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute stress discontinuities during testing.

6.6 Based on the adhesive manufacturer's recommendations and the anticipated environmental conditions, allow enough time for the adhesive to set up and reach the recommended cure. During the adhesive set and early cure

[6] Araldite Adhesive, available from Ciba-Geigy Plastics, Duxford, Cambridge, CB2 4QA, England, Hysol Epoxy Patch Kit 907, available from Hysol Div., The Dexter Corp., Willow Pass Rd., Pittsburg, CA 94565, and Scotch Weld Adhesive 1838B/A, available from 3M, Adhesives, Coatings and Sealers Div., 3M Center, St. Paul, MN 55144, have been found satisfactory for this purpose.

[7] Versiloc 201 and 204 with accelerator, available from Lord Corp., Industrial Adhesive Div., 2000 W. Grandview Blvd., P.O. Box 10038, Erie, PA 16514, have been found satisfactory for this purpose.

stage, a constant contact pressure should be maintained on the fixture. Magnetic or mechanical clamping systems work well, but systems relying on tack, such as masking tape, should be used with care to ensure that they do not relax with time and allow air to intrude between the fixture and the test area.

6.7 Scoring around the fixture violates the fundamental in-situ test criterion that an unaltered coating be tested. If scoring around the test surface is employed, extreme care is required to prevent micro-cracking in the coating, since such cracks may cause failures at diminished strengths. Scored samples constitute a different test, and this procedure should be clearly reported with the results.

6.8 Note the approximate temperature and relative humidity during the time of test.

7. Test Procedure

7.1 The general procedure for conducting pull-off tests is described in this section. More specific procedures are given in Annexes A1 to A4 for the types of testers used in the round-robin.

7.2 Select an adhesion-tester with a detaching assembly having a force calibration spanning the range of expected values along with its compatible loading fixture. Mid-range measurements are usually the best, but read the manufacturer's operating instructions before proceeding.

7.3 If a bearing ring or comparable device (5.1.3) is to be used, place it concentrically around the loading fixture on the coating surface. If shims are required when a bearing ring is employed, place them between the tester base and bearing ring rather than on the coating surface.

7.4 Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. For nonhorizontal surfaces, support the detaching assembly so that its weight does not contribute to the force exerted in the test.

7.5 Align the device according to the manufacturer's instructions and set the force indicator to zero.

NOTE 4—Proper alignment is critical, see Appendix X2. If alignment is required, use the procedure recommended by the manufacturer of the adhesion tester and report the procedure used.

7.6 Increase the load to the fixture in as smooth and continuous a manner as possible, at a rate of less than 150 psi/s (1 MPa/s) so that failure occurs or the maximum stress is reached in about 100 s or less (see Note 1).

7.7 Record the force attained at failure or the maximum force applied.

7.8 If a plug of material is detached, label and store the fixture for qualification of the failed surface in accordance with 8.3.

7.9 Report any departures from the procedure such as possible misalignment, hesitations in the force application, etc.

8. Calculation and Interpretation of Results

8.1 If instructed by the manufacturer, use the instrument calibration factors to convert the indicated force for each test into the actual force applied in units of pounds-force (1 N = 0.1 kgf).

8.2 Either use the calibration chart supplied by the manufacturer or compute the relative stress applied to each coating sample as follows:

$$X = 4F/\pi d^2$$

where:

X = greatest mean pull-off stress applied during a pass/fail test, or the pull-off strength achieved at failure. Both have units of psi (MPa = 1 N/mm^2).

F = actual force applied to the test surface as determined in 8.1, and

d = equivalent diameter of the original surface area stressed having units of inches (or millimetres). This is usually equal to the diameter of the loading fixture.

8.3 For all tests to failure, estimate the percent of adhesive and cohesive failures in accordance to their respective areas and location within the test system comprised of coating and adhesive layers. A convenient scheme that describes the total test system is outlined in 8.3.1 through 8.3.3. (See ISO 4624.)

NOTE 5—A laboratory tensile testing machine is used in ISO 4624.

8.3.1 Describe the specimen as substrate *A*, upon which successive coating layers *B*, *C*, *D*, etc., have been applied, including the adhesive, *Y*, that secures the fixture, *Z*, to the top coat.

8.3.2 Designate cohesive failures by the layers within which they occur as *A*, *B*, *C*, etc., and the percent of each.

8.3.3 Designate adhesive failures by the interfaces at which they occur as *A/B*, *B/C*, *C/D*, etc., and the percent of each.

8.4 A result that is very different from most of the results may be caused by a mistake in recording or calculating. If either of these is not the cause, then examine the experimental circumstances surrounding this run. If an irregular result can be attributed to an experimental cause, drop this result from the analysis. However, do not discard a result unless there are valid nonstatistical reasons for doing so or unless the result is a statistical outlier. Valid nonstatistical reasons for dropping results include alignment of the apparatus that is not normal to the surface, poor definition of the area stressed due to improper application of the adhesive, poorly defined glue lines and boundaries, holidays in the adhesive caused by voids or inclusions, improperly prepared surfaces, and sliding or twisting the fixture during the initial cure. Scratched or scored samples may contain stress concentrations leading to premature fractures. Dixon's test, as described in Practice D 3980, may be used to detect outliers.

8.5 Further information relative to the interpretation of the test results is given in Appendix A2.

9. Report

9.1 Report the following information:

9.1.1 Brief description of the general nature of the test, such as, field or laboratory testing, generic type of coating, etc.

9.1.2 Temperature and relative humidity and any other pertinent environmental conditions during the test period.

9.1.3 Description of the apparatus used, including: apparatus manufacturer and model number, loading fixture type and dimensions, and bearing ring type and dimensions.

9.1.4 Description of the test system, if possible, by the indexing scheme outlined in 8.3 including: product identity

and generic type for each coat and any other information supplied, the substrate identity (thickness, type, orientation, etc.), and the adhesive used.

9.1.5 Test results.

9.1.5.1 Date, test location, testing agent.

9.1.5.2 For pass/fail tests, stress applied along with the result, for example, pass or fail and note the plane of any failure (see 8.3 and ANSI N512).

9.1.5.3 For tests to failure, report all values computed in 8.2 along with the nature and location of the failures as specified in 8.3, or, if only the average strength is required, report the average strength along with the statistics.

9.1.5.4 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and criteria used.

9.1.5.5 For any test where scoring was employed, indicate it by placing a footnote superscript beside each data point affected and a footnote to that effect at the bottom of each page on which such data appears. Note any other deviations from the procedure.

10. Precision and Bias[8]

10.1 *Precision*—In an interlaboratory study of this test method, operators made measurements, generally in triplicate but in a few cases in duplicate, on coated panels covering a moderate range at the intermediate adhesion level using four different types of instruments (see Annexes A1 to A4 and Appendix X1). The number of participating laboratories varied with each instrument and in the case of one instrument with the material. Only two laboratories had access to Type I instruments but two operators in each made the triplicate tests. During the statistical analysis of the results three individual results and one set of triplicates obtained with Type II instruments were rejected as outliers; one single test with Type III instruments and three single results with Type I instruments were rejected. The pooled intra- and inter-laboratory coefficients of variation were found to be those shown in Table 1. Based on these coefficients the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

10.1.1 *Replicate Repeatability*—Triplicate results obtained by the same operator using instruments from the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

NOTE 6—Difference in percent relative to two results, x_1 and x_2, is the absolute value of

$$\frac{(x_1 - x_2)}{(x_1 + x_2)/2} \times 100.$$

10.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by operators in different laboratories using instruments of the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

10.2 *Bias*—This test method has no bias statement since there is no acceptable reference material suitable for determining the bias of this test method.

11. Keywords

11.1 adhesion; coatings; field; paint; portable; pull-off strength; tensile test

TABLE 1 Precision of Adhesion Pull-Off Measurements

Instrument	Coefficient of Variation, v, %	Degrees of Freedom	Maximum Acceptable Difference, %
Intralaboratory Instrument:			
Type IV	8.5	48	29.0
Type I, Type II, Type III	12.2	129	41.0
Total		177	
Interlaboratory Instrument:			
Type IV	8.7	20	25.5
Type I, Type II, Type III	20.6	58	58.7
Total		78	

[8] Supporting data are available from ASTM Headquarters. Request RR: D01-1094.

ANNEXES

(Mandatory Information)

A1. FIXED-ALIGNMENT ADHESION TESTER, TYPE I

A1.1 *Apparatus:*

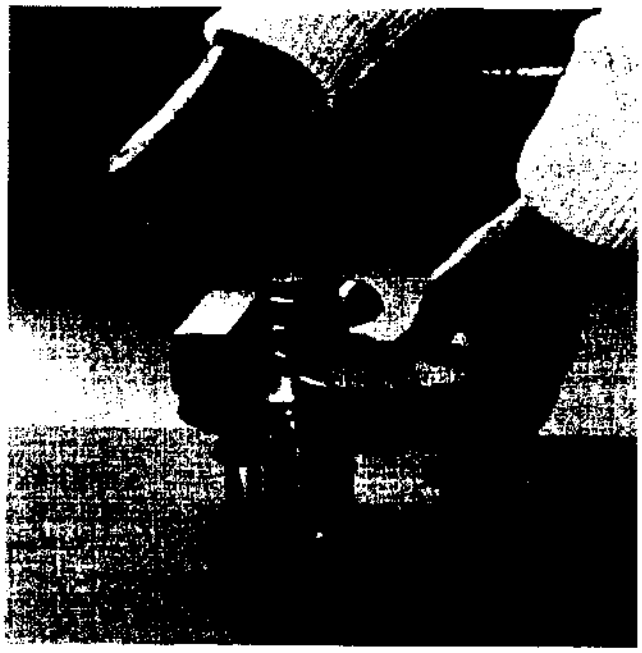
A1.1.1 A fixed-alignment portable tester as shown in Fig. A1.1[9]

NOTE A.1.1—Precision data for Type I instruments described in Table 1 were obtained using the devices illustrated in Fig. A.1.1.

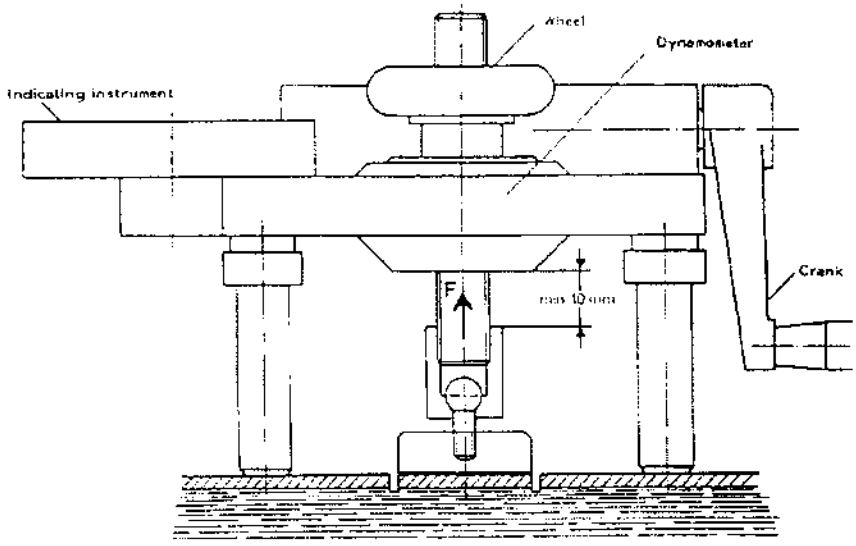
A1.1.2 The tester is comprised of detachable aluminum loading fixtures, 1.97 in. (50 mm) in diameter, screws with spherical heads that are screwed into the center of a fixture, a socket in the testing assembly that holds the head of the screw, pressure gage, dynamometer, wheel and crank.

A1.1.3 The testers are available in four models, with maximum tensile forces of 1125, 3375, 5625, and 11 250 lb (5, 15, 25, and 50 kN) respectively. For a fixture having a 1.97-in. (50-mm) diameter, a 5 kN device corresponds to a range of 0 to 360 psi (2.5 MPa).

[9] The Dyna Z5 tester is available from PROCEQ SA, Riesbachstrasse 57, CH-8034, Zurich, Switzerland.



(a)



(b)

FIG. A1.1 Photograph (a) and sketch (b) of Type I instruments

A1.2 *Procedure:*

A1.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A1.2.2 Set the pointer on the zero mark by first pressing the push-button located on the left of the indicator. While holding the push-button, turn the little knob located on the upper part of the indicator to set the pointer at zero. Set the zero after testing by pressing the push-button.

A1.2.3 After fixing a loading fixture to a substrate, insert a screw with a spherical head into the center of the fixture. Position the testing equipment on the metal disc. Then by means of the notched wheel, fix the head of the spherical screw into the socket at the base of the equipment. For the first mechanical approach, stop screwing down the wheel when the pointer on the indicator shifts from the ZERO mark. Tests are done by turning the crank. After each test, turn the crank in the opposite direction until it stops.

A2. FIXED-ALIGNMENT ADHESION TESTER TYPE II

A2.1 *Apparatus:*

A2.1.1 This is a fixed-alignment portable tester, as shown in Fig. A2.1.[10]

NOTE A2.1—Precision data for Table 1 were obtained using the devices illustrated in Fig. A2.1.

A2.1.2 The tester is comprised of detachable aluminum loading fixtures having a flat conic base that is 0.8 in. (20 mm) in diameter on one end for securing to the coating, and a circular *T*-bolt head on the other end, a central grip for engaging the loading fixture that is forced away from a tripod base by the interaction of a handwheel (or nut), and a coaxial bolt connected through a series of belleville washers, or springs in later models, that acts as both a torsion relief and a spring that displaces a dragging indicator with respect to a scale.

A2.1.3 The force is indicated by measuring the maximum spring displacement when loaded. Care should be taken to see that substrate bending does not influence its final position or the actual force delivered by the spring arrangement.

A2.1.4 The devices are available in four ranges: From 0 to 500, 0 to 1000, 0 to 2000, and 0 to 4000 psi (3.5, 7.0, 14, and 28 MPa).

A2.2 *Procedure:*

A2.2.1 Center the bearing ring on the coating surface concentric with the loading fixture. Turn the hand wheel or nut of the tester counter-clockwise, lowering the grip so that it slips under the head of the loading fixture.

A2.2.2 Align or shim the three instrument swivel pads of the tripod base so that the instrument will pull perpendicularly to the surface at the bearing ring.

A2.2.3 Take up the slack between the various members and slide the dragging (force) indicator located on the tester to zero.

A2.2.4 Firmly hold the instrument with one hand. Do not allow the base to move or slide during the test. With the other hand, turn the handwheel clockwise using as smooth and constant motion as possible. Do not jerk or exceed a stress rate of 150 psi/s (1 Mpa/s) that is attained by allowing in excess of 7 s/1000 psi (7 s/7 MPa), stress. If the 2000 or 4000 psi (14 or 28 MPa) models are used, the handwheel is replaced with a nut requiring a wrench for tightening. The wrench must be used in a plane parallel to the substrate so that the loading fixture will not be removed by a shearing force or misalignment, thus negating the results. The maximum stress must be reached within about 100 s.

A2.2.5 The pulling force applied to the loading fixture is increased to a maximum or until the system fails at its weakest locus. Upon failure, the scale will rise slightly, while the dragging indicator retains the apparent load. The apparatus scale indicates an approximate stress directly in pounds per square inch, but may be compared to a calibration curve.

A2.2.6 Record the highest value attained by reading along the bottom of the dragging indicator.

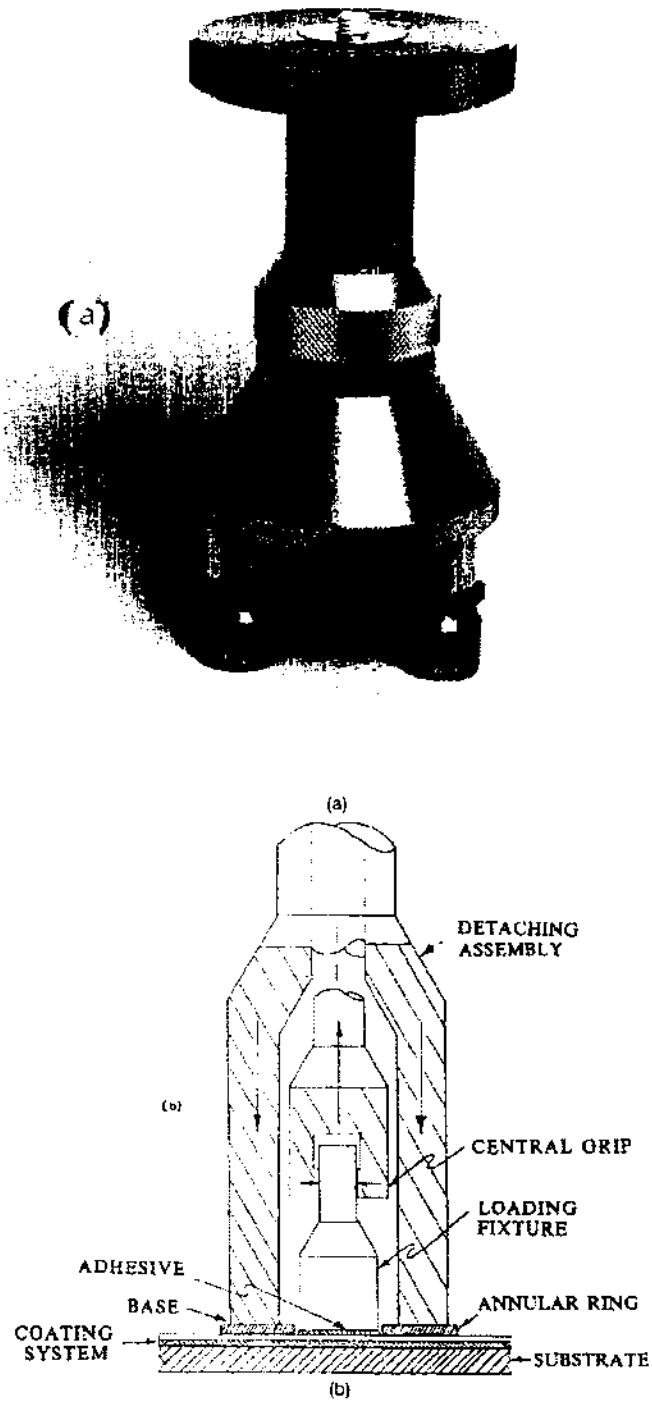


FIG. A2.1 Photograph (a) and schematic (b) of Type II, Fixed Alignment Pull-Off Tester

[10] The Elcometer, Model 106, adhesion tester is available from Elcometer Instruments, Ltd., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom, England.

A3. SELF-ALIGNING ADHESION TESTER TYPE III

A3.1 *Apparatus:*

A3.1.2 This is a self-aligning tester, as shown in Fig. A3.1.[11]

NOTE A3.1—Precision data for Type II instruments shown in Table 1 were obtained using the devices described in Fig. A3.1.

A3.1.2 Load is applied through the center of the dolly by a hydraulic piston and pin. The diameter of the piston bore is sized so that the area of the bore is equal to the net area of the dolly. Therefore, the pressure reacted by the dolly is the same as the pressure in the bore and is transmitted directly to a pressure gage.

A3.1.2 The apparatus is comprised of: a dolly, 0.75-in. (19-mm) outside diameter, 0.125-in. (3-mm) inside diameter, hydraulic piston and pin by which load is applied to the dolly, hose, pressure gage, threaded plunger and handle.

A3.1.3 The force is indicated by the maximum hydraulic pressure as displayed on the gage, since the effective areas of the piston bore and the dolly are the same.

A3.1.4 The testers are available in three standard working ranges: 0 to 1500 psi (0 to 10 MPa), 0 to 2250 psi (0 to 15 MPa), 0 to 3000 psi (0 to 20 MPa). Special dollies shaped to test tubular sections are available.

A3.2 *Procedure:*

A3.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

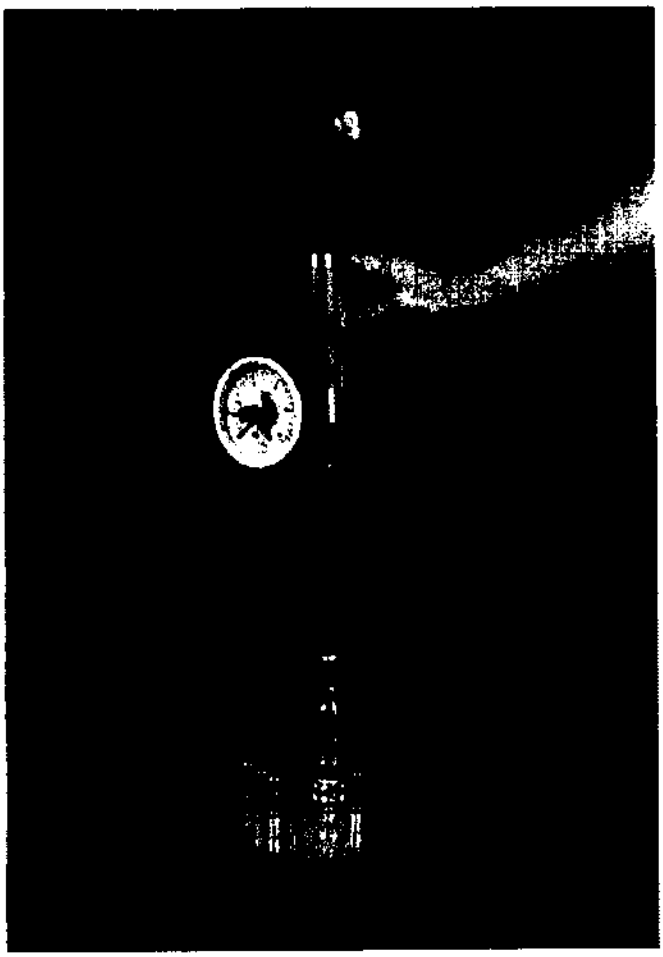
A3.2.2 Insert a decreased TFE-fluorocarbon plug into the dolly until the tip protrudes from the surface of the dolly. When applying adhesive to the dolly, avoid getting adhesive on the plug. Remove plug after holding the dolly in place for 10 s.

A3.2.3 Ensure that the black needle of the tester is reading zero. Connect a test dolly to the head and increase the pressure by turning the handle clockwise until the pin protrudes from the dolly. Decrease pressure to zero and remove the test dolly.

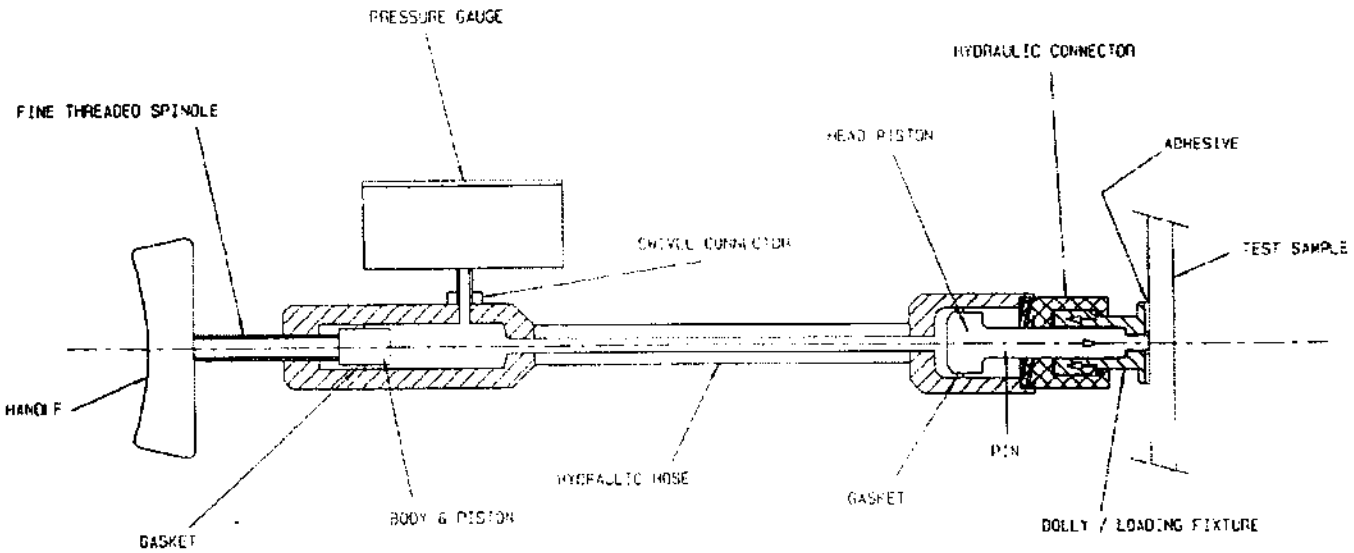
A3.2.4 Connect the head to the dolly to be tested, by pulling back the snap-on ring, pushing the head and releasing the snap-on ring. Ensure the tester is held normal to the surface to be tested and that the hose is straight.

A3.2.5 Increase the pressure slowly by turning the handle clockwise until either the maximum stress or failure is reached.

[11] The Hate Mark VII adhesion tester is available from Hydraulic Adhesion Test Equipment, Ltd., 12 Portland Square, Wapping, London, England, E1 9QR.



(a)



HYDRAULIC ADHESION TESTER

(b)

FIG. A3.1 Photograph (a) and schematic (b) of Type III, Self-Alignment Tester

A4. SELF-ALIGNMENT ADHESION TESTER TYPE IV

A4.1 *Apparatus:*

A4.1.1 This is a self-aligning tester, which may have a self-contained pressure source and has a measuring system that controls a choice of different load range detaching assemblies. It is shown in Fig. A4.1.[12]

NOTE A4.1—Precision data for Type IV instruments shown in Table 1 were obtained using the devices illustrated in Fig. A.4.1.

A4.1.2 The apparatus is comprised of: (*1*) a loading fixture having a flat cylindrical base that is 0.5 in. (12.5 mm) in diameter on one end for attachment to the test coating and a cut-off ring used with the fixture to reproducibly define the area of adhesive. The other end of the fixture has 3/8-16 UNC threads; (*2*) a central threaded grip for engaging the loading fixture through the center of the detaching assembly that is forced away by the interaction of a self-aligning seal; and (*3*) a pressurized gas that enters the detaching assembly through a flexible hose connected to a pressurization rate controller and a pressure gage (or electronic sensor).

A4.1.3 The force is indicated by the maximum gas pressure times the active area of the detaching assembly and can be directly calibrated.

A4.1.4 The detaching assemblies are available in six standard ranges in multiples of two from 0 to 500 psi (3.5 MPa) to 10 000 psi (70 MPa). Special ranges are available.

A4.1.5 Three models of control modules that control all ranges of detaching assemblies are available.

A4.2 *Procedure:*

A4.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to Type IV testers are described in the following section.

A4.2.2 Position the annular detaching assembly over the fixture attached to the coating to be tested, and loosely engage the fixture via the central threaded grip. Leave at least 1.16-in. (1.6-mm) clearance between the detaching assembly and the bottom of the threaded grip so that the seal can protrude enough to align itself when pressurized.

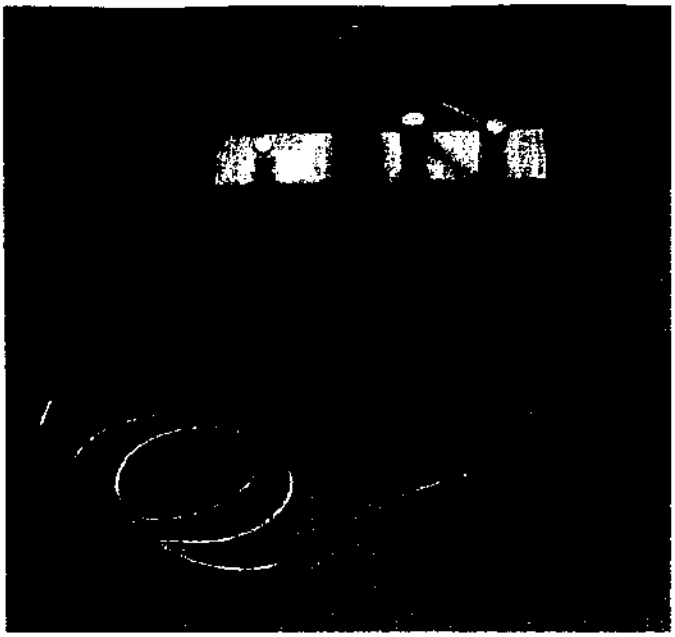
A4.2.3 Make the appropriate pneumatic connections and open the rate valve 1/4 turn.

A4.2.4 Zero the pressure measuring system.

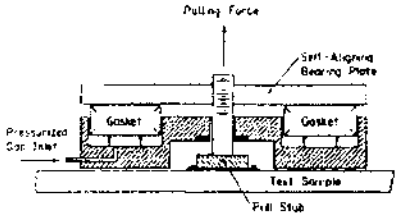
A4.2.5 Press the run button to control the gas flow to the detaching assembly and make final adjustment of rate valve so that rate of stress does not exceed 150 psi/s (1 MPa/s) yet reaches its maximum within 100 s.

A4.2.6 Record both the maximum pressure attained and the specific detaching assembly. Conversion to coating stress for ½-in. (12-mm) stud is found in a table supplied for each detaching assembly.

[12] The PATTI self-alignment adhesion tester is available from SEMicro Corp., 15817 Crabbs Branch Way, Rockville, MD 20855.



(a)



PNEUMATIC PISTON

(b)

FIG. A4.1 Photograph (a) and schematic of piston (b) of Type IV Self-Alignment Adhesion Tester

Appendix-B State DOT specifications

Appendix B-1 Georgia

February 2, 1999

SUPPLEMENTAL SPECIFICATION

SECTION 653 - THERMOPLASTIC TRAFFIC STRIPE

Delete Subsection 653.02.A.1 and substitute the following:

1. MATERIAL COMPOSITION: The binder shall consist of a mixture of synthetic resins, at least one of which is solid at room temperature, and high boiling point plasticizers. The total binder content of the thermoplastic compound shall be 18% to 35% by weight. The filler shall be white calcium carbonate and/or equivalent filler with a compressive strength of 5,000 pounds per square inch. The pigmented binder shall be well dispersed and free from all dirt, foreign objects, or other ingredients that will cause bleeding, staining, or discoloration. The binder shall be Type A - alkyd. At least 33% of the binder composition or a minimum of 8% by weight of the entire material formulation shall be a maleic-modified glycerol ester of resin. The finished thermoplastic pavement marking material shall not be adversely altered by contact with oily pavement materials or by contact from oil dropping onto the pavement surface from traffic.

Delete Subsection 653.02.A.3 and substitute the following:

3. DRYING TIME: When applied at a temperature range of 400°F to 425°F and a thickness of 1/8 inch to 3/16 inch, the material shall set to bear traffic in a maximum of 2 minutes when the air temperature is 50°F ± 3°F and shall set to bear traffic in a maximum of 10 minutes when the air temperature is 90°F ± 3°F.

Delete Subsection 653.02.A.4 and substitute the following:

4. COLOR: White thermoplastic material shall contain a minimum of 8% titanium dioxide that meets the requirements of ASTM D 476, Type II, Rutile. The white thermoplastic material shall be pure white and free from dirt or tint after solidification. The material shall not change its color and brightness characteristics after prolonged exposure to sunlight.

Delete Subsection 653.02.B.1 and substitute the following:

B. PHYSICAL REQUIREMENTS OF THERMOPLASTIC

1. COLOR: The white compound shall be pure white and free from dirt or tint. The material, when compared to the magnesium oxide standard using a standard color spetrophotometer in accordance with ASTM D 4960, shall meet the following:

Scale	Definition	Magnesium Oxide Standard	Sample
Rd	Reflectance	100	75 min.
A	Redness-Greenness	0	-5 to + 5
B	Yellowness-Blueness	0	-10 to + 10

The color of the yellow material shall match Federal Test Standard Number 595, Color 13538.

2. COLOR RETENTION: Retention of the initial color shall be determined as follows: Specimens shall be prepared and tested from samples submitted in accordance with A.STM: D 620. The ultraviolet light source shall be as specified in the test procedure, or may be a 275 watt sunlamp, with a built-in reflector. After 100 hours of exposure the test specimens shall show no perceptible color change when compared with an unexposed specimen.

3. WATER ABSORPTION: Materials shall have no more than 0.5% by weight of retained water when tested by ASTM: D570, procedure (a).

4. SOFTENING POINT: Materials shall have a softening point of not less than 175° F as determined by ASTM: E 28.

5. SPECIFIC GRAVITY: Specific Gravity of the thermoplastic compound at 25° C shall be from 1.9 to 2.5.

6. IMPACT RESISTANCE: The impact resistance shall not be less than 10 inch pounds at 77°F after the material has been heated for four hours at 400°F and cast into bars of 1-inch cross-sectional area, 3" long and placed with 1" extending above the vise in a cantilever beam (Izod type) tester using the 25 inch pound scale. This instrument is described in ASTM: D 256.

7. INDENTATION RESISTANCE: The hardness shall be measured by a Shore Durometer, Type A2, as described in ASTM D 2240. The temperature of the Durometer, 4.4 pound load and the specimen shall be maintained at 115°F. The Durometer and 4.4 pound load shall be applied to the specimen and the reading shall be between 50-75 units, after 15 seconds.

8. LOW TEMPERATURE STRESS RESISTANCE: The Contractor shall furnish sample test blocks coated with the compound by the same method as is to be used in the actual installation. The samples shall not crack or fail to adhere to the substrate when tested as follows: A sample coated with not less than 32 square inches of the compound shall be immersed in cold water for one hour, then immediately placed in a freezer chest or other insulated cold compartment and maintained at a temperature of minus 20°F for 24 hours. After 24 hours the sample shall be removed from the cold compartment and allowed to come to normal room temperature. The compound shall show no cracking or filing off when examined following the exposure cycle.

9. REHEATING: The compound shall not break down, deteriorate, scorch or discolor if held at the plastic temperature for a period of six hours at 425°F or by reason of four reheatings to the plastic temperature.

10. ABRASION RESISTANCE: The maximum loss of the material shall not exceed 0.4 grams when subjected to 200 revolutions on a Taber Abraser at 25°C, using H-22 Calibrade wheels that are weighted to 500 grams. The wearing surface shall be kept wet with distilled water throughout the test. The panel shall be prepared by forming a representative lot of material at a thickness of 0.125 inch on a 4-inch square steel plate (thickness 0.050 ± 0.001 inch) on which a primer has been previously applied.

11. YELLOWNESS INDEX: The white thermoplastic material shall not exceed a yellowness index of 0.12 in accordance with AASHTO T 250.

12. FLOWABILITY: After heating the thermoplastic material for 240 ± 5 minutes at 425°F ± 3°F and testing the flowability, the white thermoplastic shall have a maximum of 21% residue in accordance with AASHTO T 250.

13. FLOWABILITY-EXTENDED HEATING: After heating the thermoplastic material for 8.0 ± 0.5 hours at 425°F ± 3°F, while stirring the last 6 hours and testing for flowability, the thermoplastic shall have a maximum percent residue of 28 in accordance with AASHTO T 250.

14. STORAGE LIFE: The material shall meet the requirements of this specification for a period of 1 year. The thermoplastic shall also melt uniformly with no evidence of skins or unmelted particles during this 1 year period.

Delete Subsection 653.02.D and substitute the following:

D. EPOXY BINDER-SEALER: The particular type of two-part epoxy binder-sealer and the application rate shall be placed as recommended in writing by the manufacturer of the thermoplastic material.

Delete Subsection 653.03.B. and substitute the following:

B. APPLICATION

1. CLEANING: All pavement areas to be striped shall be thoroughly cleaned. Cleaning may be accomplished by the use of hand brooms, rotary brooms, air blasts, scrapers or other approved methods which leave the pavement surface thoroughly clean and undamaged. Particular care shall be taken to remove all vegetation and road film from the area to be striped. In addition, all new Portland Cement Concrete pavement surfaces shall be mechanically wire brushed or abrasive blast cleaned to remove all laitance and curing compound prior to being striped.

2. REMOVING EXISTING STRIPE: Existing traffic stripe shall be 100% removed under either of the following conditions:

   a. On Portland Cement Concrete pavement where the new stripe is to be placed at the same location as the existing marking.

   b. On all pavement where the new stripe is to be placed at a location different from the existing markings.

   Measurement and Payment for removal of Pavement Markings will be in accordance with Section 656 when shown in the Proposal as a payment item. Otherwise removal will not be paid for separately, but will be included in the payment for other work under this Section.

3. GENERAL: Thermoplastic Traffic Stripe shall not be applied when the pavement temperature in the shade is 40°F or below or when moisture on the pavement surface is present. When directed by the Engineer, Portland Cement Concrete, the Contractor shall perform a moisture test on the pavement surface. The test shall be performed as follows:

   a. Place an approximate 1 square yard of roofing felt on the pavement surface.

   b. Pour approximately ½ gallon of molten thermoplastic onto the roofing felt.

   c. After 2 minutes, lift the roofing felt and inspect to see if moisture is present on the pavement surface or underside of the roofing felt.

   d. If moisture is present, do not proceed with the striping operation until the pavement surface has dried sufficiently to be moisture free.

In order to ensure optimum adhesion, the Contractor shall apply a two-part epoxy binder-sealer on all Portland Cement Concrete pavements for either sprayed or extruded thermoplastic material. The epoxy binder-sealer shall be applied immediately in advance of, but concurrent with, the application of the thermoplastic material and shall form a continuous film over the pavement surface. In addition, the thermoplastic material shall be applied to the pavement surface in a melted state at a temperature consistent with the manufacturer's recommendations, but not less than 375°F.

The thermoplastic material shall be readily renewable by placing an overlay of new material directly over the old line of compatible material. Such new material shall bond itself to the old traffic line in such a manner that no splitting or separation takes place.

Longitudinal lines shall be offset at least 2 inches from construction joints of Portland Cement Concrete pavements.

Crosswalks, stop bars, and symbols shall have a minimum thickness of 0.094 inch at the edges and a maximum thickness of 0.188 inch at the center.

A minimum average film thickness of 0.090 inch* for lane lines, 0.060 inch* for edge lines and 0.120 inch* for gore area lines shall be maintained on all markings unless otherwise noted on the Plans. In addition, a minimum average film thickness of 0.120 inch* for lane lines, 0.090 inch* for edge lines and 0.150 inch* for gore area lines shall be maintained on all Open Graded Asphalt Concrete Friction Courses. These minimum average film thicknesses will be computed on the basis of the amount of material used each day. The glass sphere top coating shall be applied by means of a pressure type spray gun designed specifically for this purpose, and which will embed the spheres into the line surface to at least one-half their diameter. The glass spheres shall be applied at the rate of 14 pounds of spheres to each 100 square feet of thermoplastic material. It shall be the responsibility of the Contractor to supply all of the necessary auxiliary vehicles with the exception of any police units required for the operation.

(For 5 inch wide stripe)

$$\text{* Minimum Average Film Thickness (inches)} = \frac{\text{Pounds Used}}{\text{Total Linear Feet}} \times 0.236$$

(For 10 inch wide stripe)

$$\text{* Minimum Average Film Thickness (inches)} = \frac{\text{Pounds Used}}{\text{Total Linear Feet}} \times 0.118$$

Delete Subsection 653.03.C and substitute the following:

C. TOLERANCE AND APPEARANCE: Traffic stripes shall not be less than the specified width and shall not exceed the specified width by more than ½ inch. The length of the 10-foot segment for skip stripe and the 30-foot gap between segments may vary plus or minus one foot. The alignment of the stripe shall not deviate from the intended alignment by more than 1 inch on tangents and on curves up to and including one degree. On curves exceeding one degree, the alignment of the stripe shall not deviate from the intended alignment by more than 2 inches.

Work shall stop when deviation exceeds the above dimensions and the nonconforming stripe will be removed.

653.03 CONSTRUCTION: Add the following:

D. CORRECTIVE MEASURES: Thermoplastic Traffic Stripe that fails to meet Plan details or Specifications, or deviates from stated dimensions shall be corrected at no additional cost to the Department. When removal of pavement markings is necessary, it shall be performed in accordance with Section 656 and shall be placed in accordance with this Specification. No additional payment will be made for removal and replacement of unsatisfactory striping.

E. PACKAGING:

1. The material shall be delivered in 50-pound unit cardboard containers or 50-pound bags of sufficient strength to permit normal handling during shipment and transportation on the job without loss of material.
2. Each unit container shall be clearly and adequately marked to indicate the color of the material, the process batch number or similar manufacturer's identification, the manufacturer's name and address of the plant and the date of manufacture.

Delete Subsection 653.07 and substitute the following:

653.07 PAYMENT: Payment in each case as specified above shall be full compensation for the work under this Section, the cleaning and preparing of surfaces, furnishing of all materials; the application, curing and protection of traffic, including necessary warning signs, the furnishing of all tools, machines and all other equipment necessary to complete the Item.

Payment will be made under:

Item No. 653. Thermoplastic Solid Traffic Stripe,
_____Inch Wide, (Color).....per Linear Foot
Item No. 653. Thermoplastic Solid Traffic Stripe,
_____Inch Wide, (Color).....per Linear Mile
Item No. 653. Thermoplastic Skip Traffic Stripe,
_____Inch Wide, (Color).....per Gross Linear Foot
Item No. 653. Thermoplastic Skip Traffic Stripe,
_____Inch Wide, (Color).....per Gross Linear Mile
Item No. 653. Thermoplastic Pavement Markings,
Words and Symbols (Color), _____Type.....per Each
Item No. 653. Thermoplastic Traffic Stripe.....per Square Yard

Skip Traffic Stripe of the color, width and spacing shown on the Plans will be measured by the gross linear foot or gross linear mile as specified. The unpainted spaces between the stripes will be included in the overall measurements so long as the Plan ratio of 1:3 remains uninterrupted. Measurement will begin and end on a stripe.

When Traffic Stripe is to be paid for by the square yard, the actual number of square yards painted will be measured, and the space between stripes will be included in the overall measurement.

Pavement Markings, Words and Symbols, of the color specified, complete in accordance with Plan dimensions will be measured by the unit.

Linear measurements will be on the painted surface and may be made by electronic measuring device attached to a vehicle. Chord measurements not to exceed 100 linear feet will be used on curves.

652.07 PAYMENT: Payment in each case as specified above shall be full compensation for the work under this Section, the cleaning and preparing of surfaces, furnishing of all materials, including paints, beads, and thinners; the application, curing and protection of the paints, the protection of traffic including necessary warning signs; the furnishing of all tools, machines, and all other equipment necessary to complete the Item.

Payment will be made under:

Item No. 652. Solid Traffic Stripe, ____inch, (Color) (Width) .....per Linear Mile

Item No. 652. Skip Traffic Stripe, ____inch, (Color) (Width).....per Gross Linear Mile

Item No. 652. Solid Traffic Stripe, ____inch, (Color) .....per Linear Foot

Item No. 652. Skip Traffic Stripe, ____inch, (Color) .....per Gross Linear Foot

Item No. 652. Pavement Markings, Words and Symbols, (Color) .....per Each

Item No. 652. Traffic Stripe, ____inch, (Color) .....per Square Yard

SECTION 653—THERMOPLASTIC TRAFFIC STRIPE

653.01 DESCRIPTION: This work shall consist of furnishing and applying thermoplastic reflectorized pavement marking compound that is extruded or sprayed on the pavement by mechanical means and which, upon cooling to pavement temperature, produces a reflectorized pavement marking in accordance with Plan details and locations; in general conformity with these Specifications; and in accordance with the provisions of the "Manual on Uniform Traffic Control Devices."

Thermoplastic Traffic Stripe shall consist of solid or broken (skip) lines, words and/or symbols of the type, color and at the locations shown on the Plans. It is the intent of these Specifications that short lines which are defined to be crosswalks, stop bars, arrows, symbols, and crosshatching shall be extruded. All other lines, unless otherwise specified, shall be sprayed.

653.02 MATERIALS:

A. GENERAL CHARACTERISTICS: The compound shall not deteriorate upon contact with sodium chloride, calcium chloride or other chemicals used to prevent formation of ice on roadways or streets, or because of the content of pavement materials, or from petroleum droppings from traffic. In the plastic state, the material shall not give off fumes which are toxic or otherwise injurious to persons or property. The material shall not break down or deteriorate if held at the plastic temperature. The temperature versus viscosity characteristics of the plastic material shall remain constant through up to four reheatings, and shall be the same from batch to batch. There shall be no obvious change in color of the material as the result of up to four reheatings, or from batch to batch. To ensure the best possible adhesion, the compound as specified, shall be installed in a melted state at the temperature recommended by the manufacturer, but not less than 375°F., and the material shall not scorch or discolor if kept at this temperature for up to four hours.

1. MATERIAL COMPOSITION: The binder shall consist of a mixture of synthetic resins at least one of which is solid at room temperature. The total binder content of the thermoplastic compound shall be not less than 15% nor more than 35% by weight. The fillers shall be a white calcium carbonate or equivalent filler with a compressive strength of five thousand (5,000) pounds per square inch. The pigmented binder shall be well dispersed and free from all skins, dirt, foreign objects, or such ingredients as will cause bleeding, staining, or discoloration.

2. SUITABILITY FOR APPLICATION: The thermoplastic material shall be a product especially compounded for traffic markings. The markings shall not smear or spread under normal traffic conditions at temperatures below 120°F. The marking shall have a uniform cross-section. Pigment shall be evenly dispersed throughout the material. The density and character of the material shall be uniform throughout its thickness.

   The stripe shall maintain its original dimensions and placement. The exposed surface shall be free from tack and shall not be slippery when wet. The material shall not lift from the pavement in freezing weather. Cold ductility of the material shall be such as to permit normal movement with the road surface without chipping or cracking.

3. DRYING TIME: The drying time shall not exceed a characteristic straight line curve, the lower limits of which are one minute at 50°F., the upper limits of which are fifteen minutes at 90°F., both temperatures measured at a maximum relative humidity of 70%. After application and proper drying time, the material shall show no appreciable deformation or discoloration under local traffic conditions at a road temperature ranging from -20 to 140°F.

4. COLOR: White thermoplastic material shall contain a minimum of 8% titanium dioxide and, after setting, shall be pure white and free from dirt or tint. Yellow reflectorized thermoplastic material shall be "Federal Yellow" in color. The material shall not change its color and brightness characteristics after prolonged exposure to sunlight.

5. REFLECTORIZATION: During manufacture, reflectorizing glass spheres shall be mixed into the material to the extent of not less than 16 percent by weight using glass spheres having a minimum refractive index of 1.65 or not less than 25 percent by weight using glass spheres having a minimum refractive index of 1.50. Glass spheres shall also be automatically applied to the surface of the installed stripe at a minimum uniform rate of 14 pounds of glass spheres to every 100 square feet of line. For motorized equipment used to apply long lines, the glass spheres shall be expelled from a pressure type gun which will embed them into the thermoplastic material for at least ½ their diameter immediately after it has been applied to the pavement.

B. PHYSICAL REQUIREMENTS OF THERMOPLASTIC:

1. COLOR: The white compound shall be pure white and free from dirt or tint. As demonstrated by a standard color difference meter such as the Gardner Color Difference Meter, the material shall show deviations from a magnesium oxide standard not greater than the following:

Scale	Definition	Magnesium Oxide Standard	Sample
Rd	Reflectance	100	70 min.
a	Redness-Greenness	0	-5 to + 5
b	Yellowness-Blueness	0	-10 to + 10

The color of the yellow compound shall be equal to standard color chips, using Federal Test Method Standard 141, Method 4252.

2. COLOR RETENTION: Retention of the initial color shall be determined as follows: Specimens shall be prepared and tested from samples submitted in accordance with ASTM: D 620. The ultraviolet light source shall be as specified in the test procedure, or may be a 275-watt sunlamp, with a built-in reflector. After 100 hours of exposure the test specimens shall show no perceptible color change when compared with an unexposed specimen.

3. WATER ABSORPTION: Materials shall have no more than 0.5% by weight of retained water when tested by ASTM: D570, procedure (a).

4. SOFTENING POINT: Materials shall have a softening point of not less than 175°F. as determined by ASTM: E 28.

5. SPECIFIC GRAVITY: Specific Gravity of the thermoplastic compound at 25°C. shall be from 1.9 to 2.5.

6. IMPACT RESISTANCE: The impact resistance shall not be less than 10 inch-pounds at 77°F. after the material has been heated for four hours at 400°F. and cast into bars of 1-inch cross-sectional area, 3" long and placed with 1" extending above the vise in a cantilever beam (Izod type) tester using the 25 inch-pound scale. This instrument is described in ASTM: D 256.

7. INDENTATION RESISTANCE: The reading of the Shore Durometer, Type A2, as described in ASTM: D 2240 shall be not less than the amounts specified below when the material is tested after heating for four hours at 400°F. and cooled to the following temperature:

Temperature	Reading
77°F.	88

8. LOW TEMPERATURE STRESS RESISTANCE: The Contractor shall furnish sample test blocks coated with the compound by the same method as is to be used in the actual installation. The samples shall not crack or fail to adhere to the substrate when tested as follows: A sample coated with not less than 32 square inches of the compound shall be immersed in cold water for one hour, then immediately placed in a freezer chest or other insulated cold compartment and maintained at a temperature of minus 20°F. for 24 hours. After 24 hours the sample shall be removed from the cold compartment and allowed to come to normal room temperature. The compound shall show no cracking or flaking off when examined following the exposure cycle.

9. REHEATING: The compound shall not break down, deteriorate, scorch or discolor if held at the plastic temperature for a period of six hours at 425°F. or by reason of four reheatings to the plastic temperature.

10. ABRASION RESISTANCE: The material shall not show more than a maximum loss of 0.4 grams when subjected to 200 revolutions on a Tabor Abrazer at 25°C., using H-22 calibrade wheels, weighted to 500 grams. The wearing surface should be kept wet with distilled water throughout the test. The panel for this test shall be prepared by forming a representative lot of material at a thickness of 0.125 inch on a four-inch square monel panel (thickness 0.050 ± 0.001 inch) on which a suitable primer has been previously applied.

C. GLASS SPHERES PHYSICAL REQUIREMENT:

1. PREMIX GLASS SPHERES: The material shall contain either a minimum of 16% by weight of premixed glass spheres having a minimum refractive index of 1.65 or a minimum of 25% by weight of premixed glass spheres having a minimum refractive index of 1.50 meeting the following requirements:

a. ROUNDNESS:

(1) For premixed glass spheres having a minimum index of refraction of 1.65, not less than 75% of the beads, overall, and not less than 70% of the beads retained on any specific sieve shall be true spheres when tested in accordance with ASTM: D 1155.

(2) For premixed glass spheres having a minimum index of refraction of 1.50, not less than 70% of the beads overall, and not less than 60% of the beads retained on any specific sieve shall be true spheres when tested in accordance with ASTM: D 1155.

b. IMPERFECTIONS: When viewed through a 60 power microscope in the refractive index liquid, no more than 5% of the spheres shall show evidence of air inclusions, bubbles, lap lines, chill wrinkles, or other imperfections.

c. FOREIGN MATTER: The quantity of foreign matter shall not exceed 1%.

d. INDEX OF REFRACTION: The index of refraction of the premixed glass spheres shall be determined by the liquid immersion method at 25°C.

e. GRADUATION: When tested in accordance with ASTM: 1214 the beads used in the Thermoplastic material compounding shall be as follows:

U.S. Sieve Standard Sieve Size	Percent Passing
16	100
30	60-90
50	15-40
80	0-10
100	0-5

f. CHEMICAL RESISTANCE: The glass spheres shall withstand immersion in water and acids without undergoing noticeable corrosion or etching and shall not be darkened or otherwise noticeably decomposed by sulfides. The tests for chemical resistance shall consist of one (1) hour immersion in water and in corrosive agents followed by microscopic examination. A 3 to 5 gram sample shall be placed in each of three glass beakers or porcelain dishes and one covered with distilled water, on with a 3N solution of sulfuric acid and the last with a solution of 50% sodium sulfide, 48% distilled water and 2% Aerosol 1B or similar wetting agent. At the end of the one-hour immersion, no darkening, hazing or other evidence of instability shall be noticeable when examined microscopically.

2. DROP-ON GLASS SPHERES: These spheres shall meet all the requirements of Sub-Section 913.02.

D. SEALING PRIMER: The particular type of sealing primer and the proportions used shall be as recommended by the manufacturer of the thermoplastic compound.

653.03 CONSTRUCTION:

A. EQUIPMENT: The material shall be applied to the pavement by an extrusion method wherein one side of the shaping die is the pavement and the other three sides are contained by or are part of suitable equipment for heating and controlling the flow of material, or it shall be applied by spray techniques. Either method shall be so applied as to assure continuous uniformity in the dimension of the stripe. The type of application at each location shall be as designated on the Plans.

Each spray application machine must be equipped with an automatic counting mechanism capable of recording the number of linear feet of material applied to the roadway surface with an accuracy of 0.50%.

The equipment shall be constructed to provide continuous mixing and agitation of the material. Conveying parts of the equipment between the main material reservoir and the shaping die or gun shall be constructed as to prevent accumulation and clogging. All parts of the equipment which come in contact with the material shall be so constructed as to be easily accessible and exposable for cleaning and maintenance. The equipment shall be constructed so that all mixing and conveying parts up to and including the shaping die or gun maintain the material at the plastic temperature with heat transfer oil or electrical element controlled heat. No external source of direct heat will be allowed.

The equipment shall be so constructed as to ensure continuous uniformity in the dimensions of the stripe. The applicator shall provide a means for cleanly cutting off stripe ends squarely and shall provide a method of applying "skip" lines. The use of pans, aprons, or similar appliances which the die overruns will not be permitted. The equipment shall also be capable of producing varying widths of traffic markings.

Glass spheres applied to the surface of the completed stripe shall be applied by an automatic bead dispenser attached to the striping machine in such a manner that the beads are dispensed almost instantaneously upon the installed line. The glass sphere dispenser cut-off shall be synchronized with the automatic cut-off of the thermoplastic material.

Special kettle(s) shall be provided for melting and heating the thermoplastic material. The kettle(s) must be equipped with automatic thermostatic control devices so as to provide positive temperature control and prevent over-heating of the material. The applicator and kettle(s) must be so equipped and arranged as to satisfy the requirement of the National Fire Underwriters.

Applicators shall be mobile and maneuverable to the extent that straight lines can be followed and normal curves can be made in a true arc.

The applicator equipment to be used on roadway installations shall consist of either hand equipment or truck mounted units, depending on the type of marking required.

Hand equipment used for lanelines, edgelines and centerlines shall be limited to projects with small quantities and conditions that readily lend themselves to hand equipment. Hand equipment used shall be only as approved by the Engineer.

The hand equipment shall have sufficient capacity to hold 150# of molten material and shall be sufficiently maneuverable to install crosswalks; lane, edge, and center lines; arrows and legends. The truck-mounted unit for lane, edge, and center lines shall consist of a mobile self-contained unit carrying its own material capable of operating at a minimum speed of 5 miles per hour while installing striping.

B. APPLICATION:

1. GENERAL: All of the pertinent portions of Sub-Section 652.04 shall apply except as noted below:

Thermoplastic Traffic Stripe shall not be applied when the pavement temperature in the shade is 40°F. or below.

For all extruded thermoplastic, and where directed by the Engineer for sprayed thermoplastic; on old asphaltic concrete pavements where the aggregates are exposed, and on all Portland Cement Concrete pavements as directed by the Engineer, to ensure optimum adhesion, the Contractor shall apply a binder-sealer material prior to the actual thermoplastic installation. The binder-sealer material will form when applied with conventional mobile paint spraying equipment, a continuous film over the pavement surface which will dry rapidly and mechanicaly adhere to the pavement surface. The binder-sealer shall be that product currently in use and recommended by the thermoplastic material manufacturer as shown in the Qualified Products List. To ensure optimum adhesion, the thermoplastic material shall be installed in a melted state at a temperature consistent with the manufacturer's recommendations, but not less than 375°F.

The material, when formed into traffic stripes, must be readily renewable by placing an overlay of new material directly over an old line of compatible material. Such new material shall bond itself to the old line in such a manner that no splitting or separation takes place.

Longitudinal lines shall be off-set at least two inches from consruction joints of Portland Cement Concrete pavements.

Crosswalks, stop bars, and symbols shall have a minimum thickness of 3/32" at the edges and a maximum thickness of 3/16" at the center.

Minimum average film thickness of .090 inch* for lane lines, .060 inch* for edge lines and .120 inch* for gore area lines shall be maintained on all markings unless otherwise noted on the plans. This is to be computed on the basis of the amount of material used each day. The glass sphere top coating must be applied by means of a pressure type spray gun designed specifically for this purpose, and which will embed the spheres into the line surface to at least one-half their diameter. The glass spheres shall be applied at the rate of 17 pounds of spheres to each 100 square feet of compound. It shall be the

responsibility of the Contractor to supply all of the necessary auxili vehicles with the exception of any police units required for t operation.

(For 5 inch wide stripe)

*Minimum Average Film Thickness (inches) = $\frac{\text{Pounds Used}}{\text{Total Linear Feet}} \times 0.236$

(For 10 inch wide stripe)

*Minimum Average Film Thickness (inches) = $\frac{\text{Pounds Used}}{\text{Total Linear Feet}} \times 0.118$

2. CLEANING: All pavement areas to be striped shall be thorough cleaned. Cleaning may be accomplished by the use of hand broom rotary brooms, air blasts, scrapers or other approved methods whi leave the paving surface thoroughly clean and undamaged. Particul care shall be taken to remove all vegetation and road film from the ar to be striped.

3. REMOVING EXISTING STRIPE: Existing traffic stripe shall be 100 removed under either of the following conditions:

a. On Portland Cement Concrete paving where the new stripe is to b placed at the same location as the existing marking.

b. On all paving where the new strip is to be placed at a locatio different from the existing markings.

This work will be accomplished in accordance with the provisions Section 656.

c. Measurement and Payment for removal of Pavment Markings will b in accordance with Section 656 when shown in the Proposal as payment item. Otherwise removal will not be paid for separately, bu will be included in the payment for other work under this Section.

C. PACKAGING:

1. The material shall be delivered in 50-pound unit cardboard containers or 50-pound bags of sufficient strength to permit normal handling during shipment and transportation on the job without loss of material.

2. Each unit container shall be clearly and adequately marked to indicate the color of the material, the process batch number or similar manufacturer's identification, the manufacturer's name and address of the plant and the date of manufacture.

653.04 ACCEPTANCE: Segments of the Thermoplastic Traffic Stripe project which have been placed in conformance with the Plans and Specifications may be accepted, if satisfactory, 30 days after completion of all work required in that segment, and the Contractor will be relieved of any further maintenance on such segments.

653.05 CERTIFICATION: The producers of the Thermoplastic compound and glass spheres shall furnish to the Department 6 copies of certified test reports showing results of all tests specified herein, and shall further certify that the materials meet all requirements of this Section. Final acceptance, however, will be contingent upon satisfactory test results of samples obtained after delivery.

653.06 MEASUREMENT: Thermoplastic Traffic Stripe, complete in place and accepted will be measured as follows:

Solid traffic stripe of the color, width and sphere type shown on the Plans will be measured by the linear foot, linear mile, or square yard as specified. Breaks or omissions in solid lines or stripes at street or road intersections will not be measured for payment.

Skip Traffic Stripe of the color, width, spacing and sphere type shown on the Plans will be measured by the gross linear mile as specified. The unpainted space between the painted stripes will be incuded in the overall measurement so long as the Plan ratio of 1:3 (10-foot segment and 30-foot gap) remains uninterrupted. Measurement will begin and end on a stripe.

Linear measurements may be made by electronic measuring devices attached to a vehicle.

When Thermoplastic Traffic Stripe is to be paid for by the square yard the actual number of square yards painted will be measured, and the spaces between the stripes will be included in the overall measurement.

Each Thermoplastic painted word and/or symbol complete in accordance with Plan dimensions will be measured by the Unit.

653.07 PAYMENT: Payment in each case as specified above shall be full compensation for the work under this Section, the cleaning and preparation of surfaces, furnishing of all materials; the application, curing and protection from traffic, including necessary warning signs, the furnishing of all tools, machinery and all other equipment necessary to complete the Item. Payment for removal of existing stripe shall be in accordance with Sub-Section 653.03.B.3.c

Payment will be made under:

Item No. 653. Thermoplastic Solid Traffic Stripe, ____Inch Wide, (Color) ..... per Linear Foot

Item No. 653. Thermoplastic Solid Traffic Stripe, ____Inch Wide, (Color) ..... per Linear Mile

Item No. 653. Thermoplastic Skip Traffic Stripe, ____Inch Wide, (Color) ..... per Gross Linear Mile

Item No. 653. Thermoplastic Skip Traffic Stripe, ____Inch Wide, (Color) ..... per Gross Linear Mile

Item No. 653. Thermoplastic Pavement Markings, Words and Symbols (Color), ____Type ..... per Unit

Item No. 653. Thermoplastic Traffic Stripe ..... per Square Yard

Appendix B-2 **Texas**

1993 Specifications

SPECIAL PROVISION

TO

ITEM 662

WORK ZONE PAVEMENT MARKINGS

For this project, Item 662, "Work Zone Pavement Markings", of the Standard Specifications, is hereby amended with respect to the clauses cited below and no other clauses or requirements of this Item are waived or changed hereby.

Article 662.3. Materials. The first two paragraphs are voided and replaced by the following:

All non-removable markings shall be thermoplastic unless otherwise shown on the plans. Thermoplastic markings shall have a thickness of 60 mils unless otherwise shown on the plans. All non- removable work zone markings shall conform to the requirements of Item 666, "Reflectorized Pavement Markings," except for performance period, measurement and payment.

All removable markings shall be raised pavement markers, prefabricated pavement marking material, temporary flexible-reflective roadway marker tabs or other materials approved by the Engineer.

Themoplastic or paint and beads shall not be used for removable markings

Article 662.5. Construction Methods, Subarticle (1) Placement and Maintenance. The second sentence of the first paragraph is voided and replaced by the following:

The Contractor shall be responsible for maintaining all work zone pavement markings for 30 calendar days after installation. Pavement markings that fail to meet the requirements of this specification for 30 calendar days from the date of installation shall be removed and replace by the Contractor at the Contractor's expense. The 30 calendar day maintenance requirement will be required for replaced markings from the time the original markings were installed.

Article 662.6. Measurement. The second paragraph is voided and not replaced.

1995 Metric

For Routine Maintenance
Contracts Only

SPECIAL PROVISION

TO

ITEM 666

REFLECTORIZED PAVEMENT MARKINGS

For this project, Item 666, "Reflectorized Pavement Markings", of the Standard Specifications, is hereby amended with respect to the clauses cited below and no other clauses or requirements of this Item are waived or changed hereby.

Article 666.1. Description is voided and replaced by the following:

This Item shall govern for furnishing and placing reflectorized pavement markings of the types, colors, shapes, sizes, widths and thickness shown on the plans or as directed by the Engineer.

Article 666.2. Materials, Subarticle (2) Type II Marking Materials is voided and replaced by the following:

Type II markings are paint-type materials that are applied at ambient or slightly elevated temperatures. Type II marking materials shall conform to Departmental Materials Specifications D-9-8200, "Traffic Paints" and D-9-8290, "Glass Traffic Beads."

For Type I (drop on glass beads only) and Type II markings the Departmental Materials Specifications D-9-8290, "Glass Traffic Beads" dated August 1995, or later, requires a larger diameter glass bead as a part of the gradation requirements.

Article 666.2. Materials, Subarticle (3) Source of Supply. The first paragraph is voided and replaced by the following:

All Type I and Type II marking materials shall be purchased on the open market.

Article 666.2. Materials, Subarticle (3) Source of Supply. The third, fourth and fifth paragraphs are voided and not replaced.

Article 666.4. Construction Methods, Subarticle (2) Surface Preparation. The first and second paragraphs are voided and replaced by the following:

Pavement surfaces shall be cleaned to remove debris, dirt, grease and other forms of contamination prior to application of reflectorized pavement markings.

Article 666.4. Construction Methods, Subarticle (3) Application of Type I Markings, is supplemented by the following:

When shown in the plans or approved by the Engineer in writing, the Contractor shall use the following material instead of Type II marking material as a sealer for Type I markings:

An acrylic sealer consisting of an acrylic resin at 20 percent by mass of solids applied at an application rate of 0.2057 liter per square meter applied a minimum of 30 minutes before the application of the Type I marking.

Article 666.6. Measurement. The third paragraph is voided and not replaced.

Article 666.6. Measurement is supplemented by the following:

Acrylic sealer, when used as a sealer for Type I markings, shall be measured and paid for at the unit price bid for Type II markings.

Article 666.7. Payment is voided and replaced by the following:

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Reflectorized Pavement Markings" of the various types, colors, shapes, sizes, widths and thickness (Type I markings only) specified. This price shall be full compensation for furnishing all materials; for surface preparation; for application of pavement markings; and for all other labor, tools, equipment and incidentals necessary to complete the work.

1995 METRIC

SPECIAL SPECIFICATION

ITEM 6025

REFLECTORIZED PROFILE PAVEMENT MARKINGS

1. DESCRIPTION. THIS ITEM SHALL GOVERN FOR FURNISHING AND PLACING REFLECTORIZED PROFILE PAVEMENT MARKINGS OF THE TYPE, COLOR, SHAPE, SIZE, WIDTH AND THICKNESS SHOWN ON THE PLANS.

2. MATERIALS.

(1) TYPE I PROFILE MARKING MATERIALS. TYPE I PROFILE MARKINGS ARE THERMOPLASTIC TYPE MATERIALS THAT REQUIRE HEATING TO ELEVATED TEMPERATURES FOR APPLICATION. TYPE I MARKING MATERIALS SHALL CONFORM TO DEPARTMENTAL MATERIALS SPECIFICATION D-9-8220. EACH CONTAINER OF TYPE I MARKING MATERIAL SHALL BE CLEARLY MARKED TO INDICATE THE COLOR, WEIGHT, TYPE OF MATERIAL, MANUFACTURER'S NAME AND THE LOT/BATCH NUMBER.

IN ADDITION TO THE ABOVE REQUIREMENTS, THE THERMOPLASTIC TYPE MATERIAL SHALL CONTAIN A MINIMUM OF 35.0 PERCENT INTERMIX GLASS BEADS.

(2) TYPE II PROFILE MARKING MATERIALS. TYPE II PROFILE MARKINGS ARE PAINT-TYPE MATERIALS THAT ARE APPLIED AT AMBIENT OR SLIGHTLY ELEVATED TEMPERATURES.

TYPE II PAINT-TYPE PROFILE MARKINGS SHALL BE A CATALYZED METHACRYLATE OR OTHER CATALYZED MATERIAL APPROVED BY THE MATERIALS AND TESTS DIVISION AND SHALL CONTAIN A MINIMUM OF 20.0 PERCENT INTERMIX GLASS BEADS CONFORMING TO DEPARTMENTAL MATERIALS SPECIFICATION D-9-8290, AND MEET THE COLOR REQUIREMENTS FOR EACH COLOR, WHITE AND YELLOW AS SPECIFIED IN DEPARTMENTAL MATERIALS SPECIFICATION D-9-8220.

(3) SOURCE OF SUPPLY. ALL MARKING MATERIALS AND GLASS BEADS SHALL BE PURCHASED ON THE OPEN MARKET.

3. EQUIPMENT REQUIREMENTS. EQUIPMENT USED TO PLACE PAVEMENT MARKINGS SHALL:

(1) BE MAINTAINED IN SATISFACTORY OPERATING CONDITION.

(2) BE CONSIDERED IN SATISFACTORY OPERATING CONDITION IF IT HAS AN AVERAGE PLACEMENT RATE OF 1500 METERS PER HOUR OF ACCEPTABLE 100-MILLIMETER SOLID OR BROKEN LINES OVER ANY FIVE (5) CONSECUTIVE WORKING DAYS.

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(3) MEET OR EXCEED THE MATERIAL HANDLING AT ELEVATED TEMPERATURES REQUIREMENTS OF THE NATIONAL FIRE UNDERWRITERS AND THE TEXAS RAILROAD COMMISSION.

(4) BE CAPABLE OF PLACING A MINIMUM OF 12,000 METERS OF 100-MILLIMETER SOLID OR BROKEN MARKINGS PER WORKING DAY.

(5) HAVE PRODUCTION CAPABILITIES SIMILAR TO 100-MILLIMETER MARKING EQUIPMENT AND SHALL BE CAPABLE OF PLACING LINEAR MARKINGS UP TO 200 MILLIMETERS IN WIDTH IN A SINGLE PASS WHEN USED FOR PLACING MARKINGS IN WIDTHS OTHER THAN 100 MILLIMETERS.

(6) HAVE PRODUCTION CAPABILITIES CONSIDERED SATISFACTORY BY THE ENGINEER WHEN USED TO PLACE MARKINGS OTHER THAN SOLID OR BROKEN LINES.

(7) BE CAPABLE OF PLACING A CENTERLINE AND NO-PASSING BARRIER-LINE CONFIGURATION CONSISTING OF ONE (1) BROKEN LINE WITH TWO (2) SOLID LINES AT THE SAME TIME TO THE ALIGNMENT AND SPACING SHOWN ON THE PLANS.

(8) BE CAPABLE OF PLACING EDGELINES AND BROKEN LINES SIMULTANEOUSLY.

(9) BE CAPABLE OF PLACING LINES WITH CLEAN EDGES AND OF UNIFORM

CROSS-SECTION. ALL LINES SHALL HAVE A TOLERANCE OF PLUS OR MINUS THREE (3) MILLIMETERS PER 100 MILLIMETERS.

(10) HAVE AN AUTOMATIC CUT-OFF DEVICE WITH MANUAL OPERATING CAPABILITIES TO PROVIDE CLEAN, SQUARE MARKING ENDS AND TO PROVIDE A METHOD OF APPLYING BROKEN LINE IN A STRIPE-TO-GAP RATIO OF 1 TO 3. THE LENGTH OF THE STRIPE SHALL NOT BE LESS THAN THREE (3) METERS OR MORE THAN 3.2 METERS. THE TOTAL LENGTH OF ANY STRIPE-GAP CYCLE SHALL NOT BE LESS THAN 11.8 METERS OR MORE THAN 12.2 METERS.

(11) PROVIDE CONTINUOUS MIXING AND AGITATION OF THE PAVEMENT MARKING MATERIAL. THE USE OF PANS, APRONS OR SIMILAR APPLIANCES WHICH THE DIE OVERRUNS WILL NOT BE PERMITTED FOR LONGITUDINAL STRIPING APPLICATIONS.

(12) APPLY BEADS BY AN AUTOMATIC BEAD DISPENSER ATTACHED TO THE PAVEMENT MARKING EQUIPMENT IN SUCH A MANNER THAT THE BEADS ARE DISPENSED UNIFORMLY AND ALMOST INSTANTLY UPON THE MARKING AS THE MARKING IS BEING APPLIED TO THE ROAD SURFACE. THE BEAD DISPENSER SHALL HAVE AN AUTOMATIC CUT-OFF CONTROL, SYNCHRONIZED WITH THE CUT-OFF OF THE PAVEMENT MARKING EQUIPMENT.

(13) BE CAPABLE OF PRODUCING THE TYPES AND SHAPES OF PROFILES AS SPECIFIED UNDER CONSTRUCTION METHODS.

WHEN TYPE I MARKINGS ARE TO BE PLACED, THE CONTRACTOR SHALL HAVE A HAND-HELD THERMOMETER ON THE PROJECT. THE THERMOMETER SHALL BE CAPABLE OF MEASURING THE TEMPERATURE OF THE PAVEMENT MARKING MATERIAL TO BE PLACED.

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4. CONSTRUCTION METHODS.

(1) GENERAL. WHEN REQUIRED BY THE ENGINEER, THE CONTRACTOR AND THE ENGINEER SHALL REVIEW THE SEQUENCE OF WORK TO BE FOLLOWED AND THE ESTIMATED PROGRESS SCHEDULE.

MARKINGS MAY BE PLACED ON ROADWAYS EITHER FREE OF TRAFFIC OR OPEN TO TRAFFIC. ON ROADWAYS ALREADY OPEN TO TRAFFIC, THE MARKINGS SHALL BE PLACED UNDER TRAFFIC CONDITIONS THAT EXIST WITH A MINIMUM OF INTERFERENCE TO THE OPERATION OF THE FACILITY. TRAFFIC CONTROL SHALL BE AS SHOWN ON THE PLANS OR AS APPROVED BY THE ENGINEER IN WRITING. ALL MARKINGS PLACED UNDER OPEN TRAFFIC CONDITIONS SHALL BE PROTECTED FROM TRAFFIC DAMAGE AND DISFIGUREMENT.

GUIDES TO MARK THE LATERAL LOCATION OF PAVEMENT MARKINGS SHALL BE ESTABLISHED AS SHOWN ON THE PLANS OR AS DIRECTED BY THE ENGINEER. THE CONTRACTOR SHALL ESTABLISH THE PAVEMENT MARKING GUIDES AND THE ENGINEER WILL VERIFY THE LOCATION.

MARKINGS SHALL BE PLACED IN PROPER ALIGNMENT WITH THE GUIDES. THE DEVIATION RATE IN ALIGNMENT SHALL NOT EXCEED 25 MILLIMETERS PER 60 METERS OF ROADWAY. THE MAXIMUM DEVIATION SHALL NOT EXCEED 50 MILLIMETERS. INCHES NOR SHALL ANY DEVIATION BE ABRUPT.

MARKINGS SHALL ESSENTIALLY HAVE A UNIFORM CROSS SECTION. THE DENSITY AND QUALITY OF MARKINGS SHALL BE UNIFORM THROUGHOUT THEIR THICKNESS. THE APPLIED MARKINGS SHALL HAVE NO MORE THAN FIVE (5) PERCENT, BY AREA, OF HOLES OR VOIDS AND SHALL BE FREE OF BLISTERS.

TYPE I MARKINGS, IN PLACE ON THE ROADWAY, SHALL BE REFLECTORIZED BOTH INTERNALLY AND EXTERNALLY. GLASS BEADS SHALL BE APPLIED TO THE MATERIAL AT A UNIFORM RATE SUFFICIENT TO ACHIEVE UNIFORM AND DISTINCTIVE RETROREFLECTIVE CHARACTERISTICS WHEN OBSERVED IN ACCORDANCE WITH TEST METHOD TEX-828-B.

THE CONTRACTOR'S PERSONNEL SHALL BE SUFFICIENTLY SKILLED IN THE WORK OF INSTALLING PAVEMENT MARKINGS.

MARKINGS PLACED THAT ARE NOT IN ALIGNMENT OR SEQUENCE, AS SHOWN ON THE PLANS OR AS STATED IN THIS ITEM, SHALL BE REMOVED BY THE CONTRACTOR AT THE CONTRACTOR'S EXPENSE. REMOVAL SHALL BE IN ACCORDANCE WITH ITEM 677, "ELIMINATING EXISTING PAVEMENT MARKINGS AND MARKERS", EXCEPT FOR MEASUREMENT AND PAYMENT. GUIDES PLACED ON THE ROADWAY FOR ALIGNMENT PURPOSES SHALL NOT ESTABLISH A PERMANENT MARKING ON THE ROADWAY.

UNLESS OTHERWISE SHOWN ON THE PLANS, PAVEMENT MARKINGS MAY BE APPLIED BY ANY METHOD THAT WILL YIELD MARKINGS MEETING THE REQUIREMENTS OF THIS SPECIFICATION.

(2) SURFACE PREPARATION. PORTLAND CEMENT CONCRETE SURFACES SHALL BE CLEANED IN ACCORDANCE WITH ITEM 678, "PAVEMENT SURFACE PREPARATION FOR MARKINGS", TO REMOVE CURING MEMBRANE, DIRT, GREASE, OLD MARKINGS AND OTHER FORMS OF CONTAMINATION.

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PAVEMENT TO WHICH MATERIAL IS TO BE APPLIED SHALL BE COMPLETELY DRY. PAVEMENTS SHALL BE CONSIDERED DRY IF, ON A SUNNY DAY AFTER OBSERVATION FOR 15 MINUTES, NO CONDENSATION OCCURS ON THE UNDERSIDE OF A 0.3 METER SQUARE PIECE OF CLEAR PLASTIC THAT HAS BEEN PLACED ON THE PAVEMENT AND WEIGHTED ON THE EDGES.

(3) APPLICATION OF TYPE I PROFILE PAVEMENT MARKINGS. PORTLAND CEMENT CONCRETE SURFACES AND ASPHALTIC SURFACES THREE (3) YEARS OLD OR OLDER SHALL BE FURTHER PREPARED FOR TYPE I PROFILE MARKINGS, AFTER CLEANING, BY PLACING A TYPE II MARKING AS A SEALER IN

ACCORDANCE WITH ITEM 666, "REFLECTORIZED PAVEMENT MARKINGS". TYPE II MARKINGS SHALL BE PLACED A MINIMUM OF TWO (2) AND A MAXIMUM OF 30 CALENDAR DAYS IN ADVANCE OF PLACING TYPE I PROFILE MARKINGS. TYPE II MARKINGS WHICH BECOME DIRTY DUE TO INCLEMENT WEATHER OR ROAD CONDITIONS SHALL BE CLEANED BY WASHING, BRUSHING, COMPRESSED AIR OR OTHER MEANS APPROVED BY THE ENGINEER, PRIOR TO APPLICATION OF TYPE I PROFILE MARKINGS. IF WASHING IS USED, THE SURFACE OF TYPE II MARKINGS SHALL BECOME THOROUGHLY DRY BEFORE PLACING TYPE I PROFILE MARKINGS. COLOR, LOCATION AND CONFIGURATION OF TYPE II MARKINGS SHALL BE THE SAME AS THAT OF TYPE I PROFILE MARKINGS.

TYPE I PROFILE PAVEMENT MARKING MATERIAL SHALL BE APPLIED WITHIN TEMPERATURE LIMITS RECOMMENDED BY THE MATERIAL MANUFACTURER. APPLICATION OF TYPE I PROFILE PAVEMENT MARKINGS SHALL BE DONE ONLY ON CLEAN, DRY PAVEMENT HAVING A SURFACE TEMPERATURE ABOVE 10 C. PAVEMENT TEMPERATURE SHALL BE MEASURED IN ACCORDANCE WITH TEST METHOD TEX-829-B.

WHEN TYPE I PROFILE PAVEMENT MARKING APPLICATION IS BY SPRAY, AND OPERATIONS CEASE FOR FIVE (5) MINUTES OR MORE, THE SPRAY HEAD SHALL BE FLUSHED BY SPRAYING PAVEMENT MARKING MATERIAL INTO A PAN OR SIMILAR CONTAINER UNTIL THE PAVEMENT MARKING MATERIAL BEING SPRAYED IS AT THE PROPER TEMPERATURE FOR APPLICATION.

UNLESS OTHERWISE DIRECTED BY THE ENGINEER IN WRITING, TYPE I PROFILE PAVEMENT MARKING MATERIALS SHALL NOT BE PLACED ON ROADWAYS BETWEEN SEPTEMBER 30 AND MARCH 1, SUBJECT TO TEMPERATURE AND MOISTURE LIMITATIONS SPECIFIED HEREIN.

TYPE I PROFILE MARKINGS SHALL HAVE A MINIMUM THICKNESS OF 1.5 MILLIMETERS FOR EDGE LINE MARKINGS AND 2.3 MILLIMETERS FOR GORE AND CENTERLINE/NO-PASSING BARRIER LINE MARKINGS. IN ADDITION, AT A LONGITUDINAL SPACING INDICATED ON THE PLANS, THE MARKINGS SHALL BE PROFILED IN A VERTICAL MANNER SUCH THAT THE PROFILE IS TRANSVERSE TO THE LONGITUDINAL MARKING DIMENSION. THE PROFILE SHALL NOT BE LESS THAN 7.6 MILLIMETERS NOR GREATER THAN 12.7 MILLIMETER IN HEIGHT WHEN MEASURED ABOVE THE NORMAL TOP SURFACE PLANE OF THE ROADWAY. THE TRANSVERSE WIDTH OF THE PROFILE SHALL NOT BE LESS THAN 82.6 MILLIMETERS AND THE LONGITUDINAL WIDTH NOT LESS THAN 25 MILLIMETERS WHEN MEASURED AT THE TOP SURFACE PLANE OF THE MARKING. THE PROFILE MAY BE EITHER A ONE (1) OR TWO (2) TRANSVERSE BAR PROFILE. WHEN THE TWO (2) TRANSVERSE BAR PROFILE IS UTILIZED, THE SPACING BETWEEN THE BASES OF THE PROFILE BARS SHALL NOT EXCEED 12.7 MILLIMETERS. THE ABOVE TRANSVERSE BAR WIDTH IS FOR EACH 100 MILLIMETER OF LINE WIDTH.

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(4) APPLICATION OF TYPE II PROFILE PAVEMENT MARKINGS. THE APPLICATION OF TYPE II PROFILE MARKING MATERIALS SHALL BE DONE ONLY ON SURFACES WITH A MINIMUM SURFACE TEMPERATURE OF 10 C.

PRIOR TO APPLYING TYPE II PROFILE PAVEMENT MARKINGS, THE PAVEMENT SURFACE SHALL BE PREPARED BY PLACING A TYPE II PAVEMENT MARKING IN ACCORDANCE WITH ITEM 666, "REFLECTORIZED PAVEMENT MARKINGS", AS A SEALER.

IN NOT LESS THAN TWO (2) NOR MORE THAN 30 CALENDAR DAYS AFTER PLACEMENT OF THE TYPE II PAVEMENT MARKINGS SPECIFIED ABOVE, THE TYPE II PROFILE PAVEMENT MARKINGS SHALL BE PLACED. THE TYPE II PROFILE PAVEMENT MARKINGS SHALL CONSIST OF A SERIES OF TRANSVERSE DOTS A MINIMUM OF 12.7 MILLIMETERS IN BASE DIAMETER AND FIVE (5)

MILLIMETERS IN HEIGHT OR TRANSVERSE BARS A MINIMUM OF 12.7 MILLIMETERS IN BASE WIDTH AND FIVE (5) MILLIMETERS IN HEIGHT WITH A LONGITUDINAL SPACING AND PATTERN AS INDICATED ON THE PLANS. WHEN THE DOT PROFILE PATTERN IS UTILIZED, THE NUMBER OF DOTS UTILIZED TO DEFINE THE LINE WIDTH SHALL BE ONE (1) MORE THAN THE LINE WIDTH IN MILLIMETERS (EXAMPLE: FOR A 100 MILLIMETER WIDE LINE, FIVE (5) DOTS SHALL BE USED). WHEN THE BAR PROFILE IS UTILIZED, THE BAR'S TRANSVERSE LENGTH SHALL BE PLUS OR MINUS THREE (3) MILLIMETERS PER 100 MILLIMETER OF LINE WIDTH.

5. PERFORMANCE PERIOD FOR PROFILE PAVEMENT MARKINGS. PROFILE PAVEMENT MARKINGS SHALL MEET ALL REQUIREMENTS OF THIS SPECIFICATION FOR A MINIMUM OF 15 CALENDAR DAYS AFTER INSTALLATION. PAVEMENT MARKINGS THAT FAIL TO MEET ALL REQUIREMENTS OF THIS SPECIFICATION SHALL BE REMOVED AND REPLACED BY THE CONTRACTOR AT THE CONTRACTOR'S EXPENSE. THE CONTRACTOR SHALL REPLACE ALL PAVEMENT MARKINGS FAILING THE REQUIREMENTS OF THIS ITEM WITHIN 30 CALENDAR DAYS FOLLOWING NOTIFICATION BY THE ENGINEER OF SUCH FAILING. ALL REPLACEMENT MARKINGS SHALL ALSO MEET ALL REQUIREMENTS OF THIS ITEM FOR A MINIMUM OF 15 CALENDAR DAYS AFTER INSTALLATION.

6. MEASUREMENT. REFLECTORIZED PROFILE PAVEMENT MARKINGS WILL BE MEASURED BY THE METER.

   WHERE DOUBLE STRIPES ARE PLACED, EACH STRIPE WILL BE MEASURED SEPARATELY FOR PAYMENT.

   THIS IS A PLANS QUANTITY MEASUREMENT ITEM AND THE QUANTITY TO BE PAID FOR WILL BE THAT QUANTITY SHOWN IN THE PROPOSAL AND ON THE "ESTIMATE AND QUANTITY" SHEET OF THE CONTRACT PLANS, EXCEPT AS MAY BE MODIFIED BY ARTICLE 9.8 OF THE STANDARD SPECIFICATIONS. IF NO ADJUSTMENT OF QUANTITIES IS REQUIRED, ADDITIONAL MEASUREMENTS OR CALCULATIONS WILL NOT BE REQUIRED.

i

7. PAYMENT. THE WORK PERFORMED AND MATERIALS FURNISHED IN ACCORDANCE WITH THIS ITEM AND MEASURED AS PROVIDED UNDER "MEASUREMENT" WILL BE PAID FOR AT THE UNIT PRICE BID FOR "REFLECTORIZED PROFILE PAVEMENT MARKINGS" OF THE VARIOUS TYPES, COLORS, SHAPES, SIZES AND WIDTHS SPECIFIED. THIS PRICE SHALL BE FULL COMPENSATION FOR FURNISHING ALL MATERIALS; FOR APPLICATION OF PAVEMENT MARKINGS AND FOR ALL OTHER LABOR, TOOLS, EQUIPMENT AND INCIDENTALS NECESSARY TO COMPLETE THE WORK, EXCEPT AS SHOWN BELOW.

   SURFACE PREPARATION, WHEN SHOWN ON THE PLANS, WILL BE PAID FOR UNDER ITEM 678, "PAVEMENT SURFACE PREPARATION FOR MARKINGS".

Our Departmental Materials Specifications are now referred to as DMS-XXXX instead of D-9-XXXX. All reference to the Materials and Tests Division is replaced with "the Materials Section of the Construction Division (CSTM)."

TEXAS DEPARTMENT OF TRANSPORTATION

Departmental Materials Specification: DMS-8220

Thermoplastic, Hot Applied

1. **Description.** This specification shall govern for the materials, composition, quality, sampling, and testing of thermoplastic and materials utilized in its application to the roadway surface.

2. **Bidders' and/or Suppliers' Requirements.**

   (1) **Procurement by the State.** All prospective bidders and/or suppliers are notified that, before any bid is considered, the manufacturer of the material proposed for submission shall have submitted a sample of thermoplastic to the Construction Division, Materials Section (CSTM), Texas Department of Transportation (TxDOT), 3800 Jackson Avenue, Building #5, Austin, Texas 78731-6033 for evaluation. This is to ensure that the manufacturer has the technical and production capabilities to produce a material conforming to the requirements of this specification.

   (2) **Contracts.** All Contractors and/or suppliers are notified that all thermoplastic pavement marking material and other materials, utilized in the application of thermoplastic markings, shall be manufactured by a company who has previously submitted samples of the material to CSTM for evaluation. This is to ensure that the manufacturer has the technical and production capabilities to produce a material conforming to the requirements of this specification.

3. **Payment.**

   (1) **Procurement by the State.** Payment for all materials governed by this specification shall be in accordance with provisions in the purchase order awarded by the State.

   (2) **Contracts.** All materials governed by this specification utilized by the Contractor in contract projects will be paid for as prescribed in the Item, "Reflectorized Pavement Markings."

4. **Sampling and Testing.** Sampling and testing shall be in accordance with TxDOT's *Manual of Testing Procedures.* Specific tests are normally indicated in conjunction with specific specification requirements. However, TxDOT reserves the right to conduct whatever tests are deemed necessary to identify component materials and verify results of specific tests indicated in conjunction with specification requirements.

Costs of sampling and testing are normally borne by TxDOT. However, the costs of sampling and testing of materials failing to conform with the requirements of this specification shall be borne by the Contractor or supplier. Costs of sampling and testing of failing material shall be assessed at the rate established by the Director of CSTM in effect at the time of testing. Amounts due TxDOT for conducting such tests shall be deducted from monthly or final estimates on contracts or from partial or final payments on direct purchases by the State.

The values stated in either SI units or English units are to be regarded as standard. Within the test, the English units are shown in parentheses. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other.

5. Material Requirements.

(1) General Requirements. Thermoplastic pavement marking material shall be a product especially compounded for traffic markings for use on either asphaltic or Portland cement concrete surfaces. Each bag shall be clearly marked to indicate color, weight and lot, or batch number (a lot or batch shall be considered as each individual mix or blend that produces a finished product ready for use). Each bag shall contain 22.7 kilograms (50 pounds) of material. The bag shall be composed of a material which allows it to be put with its contents into the melter for use. Notification shall be given to CSTM if production lots exceed 2000 kilograms (4,500 pounds).

(2) Pigments. Prime and filler pigments shall, when washed free of resins by solvent washing, pass a U.S. Standard Sieve Number 200 and shall meet the following specific requirements for each pigment.

(a) Prime Pigments.

(i) The white pigment shall be a Rutile Titanium Dioxide.

(ii) The yellow pigment shall be a heat resistant medium chrome yellow or other approved heat-resistant pigment.

(b) Filler Pigment. The filler pigment shall be calcium carbonate, 95 percent purity.

(3) Binder. The binder shall consist of a mixture of resins, at least one of which is a solid at room temperature, and high boiling point plasticizers. At least ⅓ of the binder composition shall be a maleic-modified glyceryl ester of rosin and shall be no less than eight (8) percent by weight of the entire material formulation.

The infrared analysis of the resin extract shall match the spectra on file at CSTM.

(4) **Silica.** The total silica used in the formulation shall be in the form of glass traffic beads.

(5) **Glass Traffic Beads.** Drop-on beads shall meet the requirements of Departmental Materials Specification, DMS-8290, Glass Traffic Beads. The glass traffic beads used in the formulation shall meet the following requirements:

(a) Manufacture. Glass traffic beads shall be:

(i) Manufactured from glass

(ii) Spherical in shape

(iii) Essentially free of sharp angular particles

(iv) Essentially free of particles showing milkiness, surface scoring, or surface scratching

(v) Water-white in color

(b) Contaminants. Glass traffic beads shall:

(i) Contain less than ¼ of one (1) percent moisture by weight

(ii) Be free of trash, dirt, etc.

(iii) Show no evidence of objectionable static electricity when flowing through a regular traffic-bead dispenser

(c) Gradation.

(i) Sieve Analysis. Glass traffic beads shall meet the following gradation requirements:

Openings Micrometers	(U.S. Standard Sieves)	Percent Passing
850	(#20 Sieve)	100
600	(#30 Sieve)	80 - 95
300	(#50 Sieve)	15 - 35
150	(#100 Sieve)	0 - 4

(ii) Irregular Particles. Glass traffic beads, retained on any screen used to determine gradation requirements, shall not contain more than 30 percent (by weight) irregular particles.

(d) **Index of Refraction.** Glass traffic beads, when tested by the liquid immersion method at 25 °C (77 F), shall show an index of refraction within the range of 1.50 to 1.53.

(e) **Wetting.** Glass traffic beads shall be capable of being readily wet with water when tested in accordance with Texas Test Method Tex-826-B.

(f) **Stability.** Glass traffic beads shall show no tendency toward decomposition, surface etching, change in retroreflective characteristics, or change in color after:

(i) One hour exposure to concentrated hydrochloric acid at 25 °C (77 F)

(ii) Twenty-four hours exposure to weak alkali

(iii) One hundred hours of Weather-Ometer (Atlas, Sunshine-Type) exposure, ASTM G 23, Method 1, Type EH

6. **Finished Product Requirements.** Finished thermoplastic pavement marking materials shall meet the following requirements:

(1) **Physical Characteristics.** Unless otherwise specified, the finished thermoplastic pavement marking material shall be a free flowing granular material.

The material shall remain in the free flowing state in storage for a minimum of six months when stored at temperatures of 38 °C (100 F) or less. The material shall be readily sprayed through nozzles commonly used on thermoplastic spray equipment at temperatures between 205 and 218 °C (400 to 425 F).

(2) **Toxicity.** At temperatures up to and including 230 °C (446 F), materials shall not give off fumes which are toxic or otherwise injurious to persons, animals, or property.

(3) **Material Stability.** The material shall not break down or deteriorate when held at 205 °C (400 F) for four hours.

(4) **Temperature versus Viscosity Characteristics.** The temperature versus viscosity characteristics of the material in the plastic state shall remain constant throughout up to four (4) reheatings to 205 °C (401 F) and from batch to batch.

(5) **Chemical Resistance.** The material shall not be adversely altered by contact with sodium chloride, calcium chloride, or other similar chemicals on the roadway surface; by contact with the oil content of pavement materials; or by contact from oil dropping from traffic.

(6) **Softening Point.** The materials shall not soften at 90 °C (194 F) when tested by the Ball and Ring Method, ASTM Method E 28.

(7) **Color.** The CIE chromaticity coordinates of the material, when determined in accordance with Texas Test Method Tex-839-B, shall fall within an area having the following corner points:

	1		2		3		4		Brightness
	x	y	x	y	x	y	x	y	Y
White	.290	.315	.310	.295	.350	.340	.330	.360	Min. 65
Yellow	.470	.455	.510	.489	.490	.432	.537	.462	45-60

The white and yellow material shall meet the above specified color requirements, for each color, before and after 70 hours of exposure in a Weather-Ometer (Atlas, Sunshine-Type) fitted with an 18 - 102 (18 minutes of sunshine and rain and 102 minutes of sunshine) cyclic gear. Panels for testing shall be prepared with material as supplied.

(8) **Abrasion.** Thermoplastic pavement marking material shall have a loss between 4.0 and 12.0 grams when tested for abrasion in accordance with Texas Test Method Tex-851-B. Test according to steps one (1) through eight (8) of the procedure utilizing the following test parameters:

test distance - 127 millimeters (five [5] inches),
blast pressure - 275 kilopascal (40 psi),
sample angle - 10 degrees, and
blast media - 1200 grams

(9) **Uniformity.** Material shall be manufactured such that, when sampled in accordance with the TxDOT's *Manual of Testing Procedures*, any 100-gram sample will be representative of the batch or lot of material.

7. **Formula:** Thermoplastic Marking Material

White	Percent by Weight
Binder	18 - 23
Titanium Dioxide	12 - 15
Calcium Carbonate	20 - 42
Glass Traffic Beads	30 - 45
Total	100

Yellow	Percent by Weight
Binder	18 - 23
Medium Chrome Yellow	10 - 15
Calcium Carbonate	20 - 42
Glass Traffic Beads	30 - 45
Total	100

Appendix B-3 **California**

Standard Specifications

STATE OF CALIFORNIA

BUSINESS, TRANSPORTATION AND HOUSING AGENCY

DEPARTMENT OF TRANSPORTATION

JULY, 1995

Issued by

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SECTION 84
TRAFFIC STRIPES AND PAVEMENT MARKINGS

84-1 GENERAL

84-1.01 Description.—This work shall consist of applying painted and thermoplastic traffic stripes (traffic lines) and pavement markings at the locations and in accordance with the details shown on the plans or designated by the Engineer, and as specified in these specifications and the special provisions.

The kind of material, paint or thermoplastic, to be applied will be designated in the contract item, specified in the special provisions, or shown on the plans.

For the purposes of this Section 84, "Traffic Stripes and Pavement Markings," traffic stripes (traffic lines) are defined as longitudinal centerlines and lanelines which separate traffic lanes in the same or opposing direction of travel, and longitudinal edgelines which mark the edge of the traveled way or the edge of the lanes at gore areas separating traffic at exit and entrance ramps. Pavement markings are defined as transverse markings which include, but are not limited to, word and symbol markings, limit lines (stoplines), crosswalk lines, shoulder markings, parking stall markings, and railroad grade crossing markings.

84-1.02 Control of Alignment and Layout.—All work necessary to establish satisfactory alignment for stripes and all layout work required for pavement markings shall be performed by the Contractor with any device or method that will not damage the pavement nor conflict with other traffic control devices.

84-1.03 Tolerances and Appearance.—Traffic stripes and pavement markings shall conform to the dimensions and details shown on the plans.

Completed traffic stripes shall have clean and well-defined edges without running or deformation, shall be uniform, shall be straight on tangent alignment, and shall be on a true arc on curved alignment. The widths of completed traffic stripes shall not deviate more than 6 mm on tangent nor more than 12 mm on curves from the widths shown on the plans. Broken traffic stripes shall also conform to the following requirements:

A. The lengths of the gaps and individual stripes that form broken traffic stripes shall not deviate more than 50 mm from the lengths shown on the plans.

B. The lengths of the gaps and individual stripes shall be of such uniformity throughout the entire length of each broken traffic stripe that a normal striping machine will be able to repeat the pattern and superimpose additional stripes upon the traffic stripe being applied.

The completed pavement markings shall have clean and well-defined edges without running or deformation and shall conform to the dimensions shown on the plans, except that minor variations may be accepted by the Engineer.

Drips, overspray, improper markings, and paint and thermoplastic material tracked by traffic shall be immediately removed from the

pavement surface by methods approved by the Engineer. All this removal work shall be at the Contractor's expense.

84-1.04 Protection From Damage.—The Contractor shall take special care to protect existing reflective pavement markers and shall, at the Contractor's expense, replace all coated markers.

Newly placed traffic stripes and pavement markings shall be protected from damage by public traffic or other causes until the paint is thoroughly dry or the thermoplastic material has sufficiently hardened.

84-2 THERMOPLASTIC TRAFFIC STRIPES AND PAVEMENT MARKINGS

84-2.01 Description.—This work shall consist of furnishing and applying thermoplastic traffic stripes and pavement markings, including glass beads.

84-2.02 Materials.— The thermoplastic material shall conform to either State Specification ~~8010-21C-21~~ or ~~8010-21C-19~~. Glass beads to be applied to the surface of the molten thermoplastic material shall conform to the requirements of State Specification 8010-21C-22 (Type II). → 8010-01A

State Specifications for thermoplastic material and glass beads may be obtained from the Transportation Laboratory, P.O. Box 19128, Sacramento, CA 95819, Telephone No. (916) 227-7000.

84-2.03 (Blank)

84-2.04 Application.— Existing surfacing which is to receive the thermoplastic material shall be mechanically wire brushed to remove all dirt and contaminants. Surfaces of new portland cement concrete pavement to receive the thermoplastic material shall be mechanically wire brushed or abrasive blast cleaned to remove all laitance and curing compound.

Existing pavement markers which are damaged by blast cleaning or wire brushing shall be removed and replaced by the Contractor at the Contractor's expense.

Thermoplastic material shall be applied only to dry pavement surfaces and only when the pavement surface temperature is above 10°C.

A primer, of the type recommended by the manufacturer of the thermoplastic material, shall be applied to all asphaltic surfaces over 6 months old and to all portland cement concrete surfaces. The primer shall be applied immediately in advance of, but concurrent with, the application of thermoplastic material. The primer shall be applied at the application rate recommended by the manufacturer and shall not be thinned.

Preheaters with mixers having 360 degree rotation shall be used to preheat material.

The thermoplastic material shall be applied to the pavement at a temperature between 200°C and 220°C, unless a different temperature is recommended by the manufacturer.

The thermoplastic material shall be applied by either spray or extrusion methods in a single uniform layer.

Stencils shall be used when applying thermoplastic material for pavement markings.

The pavement surface to which thermoplastic material is applied shall be completely coated by the material and the voids of the pavement surface shall be filled.

Unless otherwise specified in the special provisions, the thermoplastic material for traffic stripes shall be applied at a minimum thickness of 1.5 mm. Thermoplastic material for pavement markings shall be applied at a thickness of 2.5 to 3.8 mm. Glass beads shall be applied immediately to the surface of the molten thermoplastic material at a rate of not less than 4 kg per 10 m^2. The amount of glass beads applied shall be measured by stabbing the glass bead tank with a calibrated rod.

84-2.05 Measurement.— Thermoplastic traffic stripes will be measured by the meter along the line of the traffic stripes, without deductions for gaps in broken traffic stripes. A double traffic stripe, consisting of two 100-mm wide yellow stripes, will be measured as 2 traffic stripes.

Thermoplastic pavement markings will be measured by the square meter for the actual area covered.

84-2.06 Payment.— The contract prices paid per meter for thermoplastic traffic stripes of the widths and patterns designated in the Engineer's Estimate and per square meter for thermoplastic pavement markings shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in applying thermoplastic traffic stripes and pavement markings, complete in place, including establishing alignment for stripes, and layout work, as shown on the plans, as specified in these specifications and the special provisions, and as directed by the Engineer.

84-3 PAINTED TRAFFIC STRIPES AND PAVEMENT MARKINGS

84-3.01 Description.— This work shall consist of painting traffic stripes and pavement markings, including applying glass beads.

84-3.02 Materials.— Paint for traffic stripes and pavement markings shall conform to the following State Specifications:

	State Specification No.
Fast Dry Solvent Borne— White, Yellow, and Black	8010-51K-04
Rapid Dry Solvent Borne— White and Yellow	8010-51K-02
Rapid Dry Water Borne— White, Yellow and Black	8010-91D-30

Glass beads shall conform to State Specification No. 8010-21C-22 (Type II).

Copies of State Specifications for traffic paint and glass beads may be obtained from the Transportation Laboratory, P.O. Box 19128, Sacramento, CA 95819, Telephone No. (916) 227-7000.

The kind of paint to be used (solvent borne or water borne) shall be determined by the Contractor based on the time of year the paint is applied and local air pollution control regulations.

Solvent borne white and yellow paint shall be either the Fast Dry or Rapid Dry type at the option of the Contractor.

Thinning of paint will not be allowed.

Paint shall be tested prior to use or the manufacturer shall provide the Engineer with a Certificate of Compliance in accordance with the provisions of Section 6-1.07, "Certificates of Compliance." The certificate shall certify that the paint complies with the specifications and that paint manufactured to the same formulation and process has previously

passed State testing. A list of manufacturers that have produced paint meeting State specifications is available from the Transportation Laboratory. (Material supplied by manufacturers other than those that have manufactured approved paint will require complete testing.)

84-3.03 Mixing.— Mechanical mixers shall be used to mix paint. Prior to applying, the paint shall be mixed a sufficient length of time to thoroughly mix the pigment and vehicle together, and shall be kept thoroughly agitated during its application.

84-3.04 Application Equipment.— Mechanical means shall be used to paint traffic stripes and pavement markings and to apply the glass beads for traffic stripes.

All equipment used in the application of traffic stripes and pavement markings shall produce stripes and pavement markings of uniform quality that conform to the specified requirements.

Stencils and hand spray equipment shall be used to paint pavement markings. Stencils shall conform to the dimensions shown on the plans.

The striping machine shall be capable of accurately superimposing succeeding coats of traffic paint upon the first coat and upon existing stripes at a speed of at least 8 km/h.

The striping machine shall consist of a rubber-tired vehicle that is maneuverable to the extent that straight lines can be followed and normal curves can be made in true arcs. It shall be capable of applying traffic paints and glass beads at the rates specified. The striping machine shall be equipped with the following: (a) a pointer or sighting device not less than 1.5 m long and extending from the front of the machine; (b) a pointer or sighting device extending from the side of the machine to gauge the distance from the centerline for painting shoulder stripes; (c) a positive acting cutoff device to prevent depositing paint in gaps of broken stripes; (d) shields or an adjustable air curtain for line control; (e) pressure regulators and gages (if pneumatically operated) that are in full view of the operator; (f) a paint strainer in the paint supply line; (g) a paint storage tank with a mechanical agitator that operates continuously during painting operations; (h) a glass bead dispenser located behind the paint applicator nozzle and which is controlled simultaneously with the paint applicator nozzle; and (i) calibrated rods for measuring the volumes of paint and glass beads in the paint and glass bead tanks.

All spray equipment shall be of a proper type and of adequate capacity for the work. Air atomized spray equipment shall be equipped with oil and water extractors and pressure regulators and shall have adequate air volume and compressor recovery capacity. Spray gun tip needle assemblies and orifices shall be of the proper sizes.

Attention is directed to Section 5-1.11, "Alternative Equipment," of the Standard Specifications.

Where the configuration or location of a traffic stripe is such that the use of a striping machine is unsuitable, traffic paint and glass beads may be applied by other methods and equipment approved by the Engineer. The Engineer will determine if the striping machine is unsuitable for a particular use.

84-3.05 Application.— Traffic stripes and pavement markings shall be applied only on dry surfaces and only during periods of favorable weather. Painting shall not be performed when the atmospheric temperature is below 5°C when using solvent borne paint or below 10°C

when using water borne paint; when freshly painted surfaces may become damaged by rain, fog, or condensation; nor when it can be anticipated that the atmospheric temperature will drop below the above 5°C or 10°C temperatures during the drying period.

Surfaces which are to receive traffic stripes and pavement markings shall be cleaned of all dirt and loose material.

Solvent borne paint shall not be heated to a temperature greater than 70°C. Water borne paint shall not be heated to a temperature greater than 65°C.

A one-coat 75-mm wide black stripe shall be painted between the two 100-mm wide yellow stripes of a double traffic stripe. If the two 100-mm wide yellow stripes are to be applied in 2 coats, the black stripe shall be applied concurrently with the second coat of yellow stripes.

On new surfacing, pavement markings and traffic stripes (except the black stripe between the yellow stripes of a double traffic stripe) shall be applied in 2 coats unless otherwise shown on the plans. The first coat of paint shall be dry before application of the second coat.

On 2-lane highways, when the first coat of the centerline stripe is applied in the same direction as the kilometer posts increase, the right-hand spray gun of the 3 spray guns used to apply double yellow stripe shall be used to apply a single yellow stripe. When the first coat of the centerline stripe is applied in the same direction as the kilometer posts decrease, the left-hand spray gun of the 3 spray guns used to apply double yellow stripe shall be used to apply a single yellow stripe. The second coat of centerline striping shall be applied in the opposite direction that the first coat was applied.

On existing surfacing, pavement markings and traffic stripes shall be applied in one coat.

Each coat of paint for any traffic stripe, including glass beads where required, shall be applied in one pass of the striping machine, regardless of the number, widths, and patterns of individual stripes involved.

Paint to be applied in one coat shall be applied at an approximate rate of one liter per 3 m^2.

Paint to be applied in 2 coats shall be applied approximately as follows:

	Square Meter Coverage Per Liter	
	First Coat	*Second Coat*
Solvent Borne Paint	10	5
Water Borne Paint	6	6

The exact rate of paint to be applied will be determined by the Engineer. The volume of paint applied shall be measured by stabbing the paint tank with a calibrated rod. At the option of the Engineer, if the striping machine is provided with paint gages, the volume of paint may be determined by using the gages.

Unless otherwise directed by the Engineer, glass beads shall be uniformly incorporated in all coats of paint concurrently with the application of the paint, except that glass beads shall not be applied to black paint. Beads shall be embedded in the coat of traffic paint being applied to a depth of one-half their diameters.

Glass beads shall be applied at an approximate rate of 0.6-kg per liter

of paint. The exact rate will be determined by the Engineer. The amount of glass beads applied shall be measured by stabbing the glass bead tank with a calibrated rod.

84-3.06 Measurement.— Painting traffic stripes will be measured by the meter along the line of the traffic stripes, without deductions for gaps in broken traffic stripes. A double traffic stripe, consisting of two 100-mm wide yellow stripes separated by a 75-mm wide black stripe, will be measured as one traffic stripe. Painted pavement markings will be measured by the square meter for the actual area painted.

84-3.07 Payment.— The contract prices paid per meter for paint traffic stripe and per square meter for paint pavement marking, of the number of coats designated in the Engineer's Estimate, shall include full compensation for furnishing all labor, materials, tools, equipment and incidentals, and for doing all the work involved in painting traffic stripes (regardless of the number, widths, and patterns of individual stripes involved in each traffic stripe) and pavement markings including establishing alignment for stripes, and layout work, complete in place, as shown on the plans, as specified in these specifications and the special provisions, and as directed by the Engineer.

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8010 -01A
July 1997

SPECIFICATIONS FOR

Thermoplastic Traffic Striping Material, Hydrocarbon Binder, White and Yellow

1.0 SCOPE This specification covers a reflectorized thermoplastic pavement striping material that is applied to portland cement or asphalt concrete road surfaces in a molten state by mechanical means. Upon cooling to normal pavement temperature this produces and adherent reflectorized stripe capable of resisting deformation by traffic.

2.0 SPECIFICATION AND STANDARDS Specifications and standards referenced in this document in effect on opening of the Invitation for Bid form a part of this specification where referenced.

3.0 REQUIREMENTS

3.1 Composition: The thermoplastic material shall be 100 percent solids. The binder shall consist of synthetic hydrocarbon resins, and be homogeneously incorporated with all the necessary prime pigments, fillers and glass beads to produce a traffic coating to meet the requirements as specified herein.

3.2 Form: The thermoplastic material shall be supplied in either block or granular form as required in the purchase request.

3.3 Application Type: The thermoplastic material shall be formulated as required in the purchase request.

3.4 Characteristics of the Finished Thermoplastic: California Test Method 423 unless otherwise specified.

		White	Yellow
3.4.1	Glass Beads, AASHTO M247 TYPE 1, percent by weight	25-30	25-30
3.4.2	Inert fillers, insoluble in hydrochloric acid, % pass, USA Standard Sieve 150μm ASTM E11	100	100
3.4.3	Binder, percent by weight, minimum	18	18
3.4.4	Specific Gravity, maximum	2.15	2.15
3.4.5	Ring and Ball softening point ASTM E28, °C	93-121	93-121

Cancels & Supersedes 8010-21C-21 and 8010-01
>Indicates Revision (Excluding State Spec. No. and Date)

3.4.6	Tests on material after 4 hours heat with stirring at 218°C ± 1°C, which includes 1 hour for meltdown and temperature stabilization.		
3.4.6.1	Tensile bond strength to an unprimed sand blasted portland cement concrete block, 3.2 mm thick film drawndown at 218°C, tested at 24° ±1°C MPa, minimum	1.24	1.24
3.4.6.2	Brookfield Thermosel Viscosity, Spindle SC4-27, 20 RPM at 218°C, Pa.S		
	Extruded Type	4.5-10	4.5-10
	Low Viscosity Type, maximum	3.0	3.0
		White	Yellow
3.4.6.3	Impact Resistance, ASTM D2794, 3.2mm thick film drawndown at 218°C on an unprimed sandblasted, portland cement concrete block, male identor 15.9mm, no female die. Test at 24° ± 1°C, kg-m with no cracks or bond loss, minimum.	0.58	0.58
3.4.6.4	Daylight Luminous Reflectance AASHTO Designation: T 250-94, minimum	80	----
3.4.6.5	Color-yellow, shall match Fed 595, color No. 33538 and chromaticity limits shall lie within HUE = 580-583.5 nm, Chroma x =0.7050-0.5000 y and brightness Y =42-59 measured according to California test method Cal 660.	----	----
3.4.6.6	Yellow Index, AASHTO Designation: T 250-94 calculated as Y.I.=100(A-B)/G, maximum	10	
3.4.6.7.	Ultra Violet Light and Condensate Exposure, ASTM G53 . 300 hours total: alternate 4 hours UV exposure at 60°C, 4 hours condensate at exposure at 60°C.		
	White – yellowness index, maximum	20	-----
	Yellow – must meet chromaticity limits as specified in 3.4.6.5.	-----	Pass
3.4.6.8	Abrasion Test – 400 grs. Glass beads, 600-850μm, 0.15 Mpa air pressure, and cast sample 12.7cm x 12.7 cm x 0.95cm g loss, maximum.	10	10
3.4.6.9	Hardness Harness, Shore A-2 Durometer with 2 Kg weight at 46°C	45-75	45-75

3.5 Other Requirements: The thermoplastic material shall readily apply or spray at temperatures between 204°C -232°C .

When applied to the pavement, the thermoplastic material shall be sufficiently tack-free to carry traffic in not more than 2 minutes when pavement surface temperature is at 10°C, and not more than 10 minutes when pavement surface temperature is 54°C.

When tested according to California Waste Extraction Test, Title 26, California Code of Regulations Section 22-66700, granular yellow thermoplastics shall have an extractable lead content of less than 0.3mg/L.

3.6 Workmanship: The pigment, beads, and fillers shall be well dispersed in the binder. The material shall be free from all skins, dirt, foreign objects, and other deleterious substances, and shall be of such composition that it will not bleed, stain, or discolor when applied to pavements.

Thermoplastic material shall not emit fumes which are toxic or injurious to persons or property when it is heated to application temperature. The material shall not emit excessive smoke during heating or application.

3.7 Shelf Life: The material shall maintain the requirements of this specification for a minimum period of one year. Any materials failing to do so shall be replaced by the manufacturer at his expense.

3.8 Air pollution compliance: This material shall comply with all applicable air pollution control rules and regulations.

3.9 Material Data Safety Sheets: Material Data Safety Sheets shall be provided by the manufacturer to include Health Harzard information on the material when it is heated to application temperature.

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection: The minimum size batch of thermoplastic traffic striping material sampled and tested shall not be less than 907kg unless the total order is less than this amount.

All thermoplastic material intended for use by the State of California must be sampled and approved by the Transportation Laboratory before shipment. Manufacturers within the State of California must contact the Berkeley or Los Angeles Inspection Office for sampling procedures.

Manufacturers outside the State of California must submit the following information before shipment.

1. State specification number
2. Color, white and yellow and tons of each
3. Form - block or granular
4. Type – extruded or low viscosity
5. Exact address of shipment
6. Number and identification of batches comprising shipment
7. Date of manufacture
8. Purchase order or contract number

The above information is to be sent to, Office of Materials Engineering and Testing Services, 5900 Folsom Boulevard, Sacramento CA 95819. On delivery, the thermoplastic will be sampled for compliance to specification. Material not meeting the specification shall be removed and replaced by the manufacturer at his expense, including all cost for handling, testing and shipping.

4.2 Testing: All tests shall be performed according to the specified test method, latest revision. Qualitative and quantitative analysis may also be performed by X-ray diffraction, X-ray emission, infrared and other instrumental methods of analysis, at the option of the Department of Transportation.

5. PREPARTION FOR DELIVERY

5.1 Packaging:

5.1.1 Block Form: The thermoplastic material shall be packaged in suitable containers to which it will not adhere nor interact with during shipment or storage. The blocks of cast thermoplastic material shall be approximately 89x30x5 cm and shall weigh approximately 23kg.

5.1.2 Granular Form: The thermoplastic material shall be packaged in meltable bags, which are compatible with the thermoplastic and shall weigh approximately 23kg. The containers must have sufficient strength and be properly sealed to prevent breakage and leakage during normal handling.

5.2 Marking: Each container label shall include: State Specification Number, color, type of binder, low viscosity type or extrusion type, manufacturer's name and address, date of manufacture, and batch number. All markings on containers shall be legible and permanent. Markings shall not smear or rub off container. Containers failing to meet marking requirements will not be accepted.

The containers and labeling shall meet all applicable U.S. Department of Transportation and Interstate Commerce Commission regulations. Concerning the contents, each container shall be labeled with such warnings or precautions as are required by local, state and Federal laws and regulations.

6. NOTES

6.1 Certificate of Compliance: The manufacturer of thermoplastic materials shall furnish the Engineer with a Certificate of Compliance in conformance with the provisions of the Department of Transportation Standard Specifications, July 1995, Section 6-1.07, "Certificate of Compliance". The certificate shall also include a list, by title and section, of all applicable state and federal packaging and labeling laws and a statement that all requirements have been meet.

Certificates of Compliance shall be sent of California Department of Transportation, Office of Materials Engineering and Testing Services, 5900 Folsom Blvd., Sacramento, California 95819.

6.2 The Contractor shall assume all costs arising from the use of patented materials, equipment, devices or processes used on or incorporated in the work, agrees to indemnify and save harmless the State of California and its duly authorized representatives from all suits at law or action of every nature for or on account of the use of any patented materials, equipment, devices or processes.

Appendix B-4 Louisiana

NOTE: THESE SPECIFICATIONS INCLUDE PROPOSED REVISIONS EXPECTED TO BE ADOPTED BY THE LOUISIANA DOTD.

1015.10 THERMOPLASTIC PAVEMENT MARKINGS.

(a) Description: This specification covers hot-sprayed or hot-extruded reflective thermoplastic compound for pavement markings on asphaltic or portland cement concrete pavement. Thermoplastic marking material applied to asphaltic surfaces shall consist of an alkyd based formulation. Thermoplastic marking material applied to portland cement concrete surfaces shall consist of either an alkyd based or hydrocarbon based formulation. Material shall be so manufactured as to be applied by spray or extrusion to pavement in molten form, with internal and surface application of glass spheres, and upon cooling to normal pavement temperature, shall produce an adherent, reflectorized pavement marking of specified thickness and width, capable of resisting deformation.

Material shall not scorch, break down, or deteriorate when held at the plastic temperature specified in Subsection 732(03)(d)(1) for 4 hours or when reheated four times to the plastic temperature. Temperature-vs-viscosity characteristics of plastic material shall remain constant when reheated four times, and shall be the same from batch to batch. There shall be no obvious change in color of material as the result of reheating four times or from batch to batch.

(b) Suitability for Application: Thermoplastic material shall be a product especially compounded for pavement markings. Markings shall maintain their original dimension and placement and shall not smear or spread under normal traffic at temperatures below 140°F. Markings shall have a uniform cross section. Pigment shall be evenly dispersed throughout its thickness. The exposed surface shall be free from tack and shall not be slippery when wet. Material shall not lift from pavement in freezing weather. Cold ductility of material shall be such as to permit normal movement with the pavement surfaced without chipping or cracking.

(c) Standard Thermoplastic Pavement Markings: Materials shall be approved products listed in QPL 63 and shall conform to AASHTO M 249 and the specifications as stated herein with the following modifications:

(1) Color: The yellow thermoplastic shall conform to the requirements of the following table when tested in accordance with ASTM E 1349.

Color Specification Limits (Daytime)								
Color	1		2		3		4	
	x	y	x	y	x	y	x	y
Yellow	0.4756	0.4517	0.4985	0.4779	0.5222	0.4542	0.4919	0.4354

(The four pairs of chromaticity coordinates determine the acceptable color in terms of the CIE 1931 Standard Colorimetric System measured with Standard Illuminant C.)

(2) Whiteness Index: The white thermoplastic shall have a minimum whiteness index of 40 when tested according to ASTM E 313.

(d) Inverted Profile Thermoplastic Pavement Markings: Materials shall be approved products listed in QPL 63 and shall conform to AASHTO M 249 and the specifications as stated herein with the following modifications:

(1) Bead Content:

U.S. Standard Sieve Size (Microns)	Class A -- 10% min. (by wt.) of thermoplastic compound, Percent Retained	Class B -- 25% min.(by wt.) of thermoplastic compound
14 (1400)	0-1	Beads shall meet gradation requirement of AASHTO M247, Type I.
16 (1190)	0-20	
18 (1000)	0-45	
20 (840)	30-80	
30 (595)	20-50	
Pan	0-10	

(2) Bead Quality: The glass beads shall be coated with A-116 Silane or other adhesion promoting coating. The glass beads shall have a maximum of 3% irregular particles and a maximum of 5% air inclusions. The percentage of true spheres shall be 90% minimum for Class A beads and 80% minimum for Class B beads.

(3) Binder Content: The binder content of the thermoplastic material shall be 19% minimum.

(4) Titanium Dioxide: The titanium dioxide shall meet ASTM D476, Type II, Rutile grade - 93% minimum titanium content.

(5) Yellow Pigment: The yellow pigment for the yellow thermoplastic material shall be 4% minimum.

(6) Color: The yellow thermoplastic shall conform to the requirements of the following table when tested in accordance with ASTM E 1349.

Color Specification Limits (Daytime)								
Color	1		2		3		4	
	x	y	x	y	x	y	x	y
Yellow	0.4756	0.4517	0.4985	0.4779	0.5222	0.4542	0.4919	0.4354

(The four pairs of chromaticity coordinates determine the acceptable color in terms of the CIE 1931 Standard Colorimetric System measured with Standard Illuminant C.)

(7) Whiteness Index: The white thermoplastic shall have a minimum whiteness index of 40 when tested according to ASTM E 313.

(8) Specific Gravity: The specific gravity of the thermoplastic pavement marking material shall not exceed 2.35.

(9) Flowability: After heating the thermoplastic material for four (4) hours ±5 minutes at 425°±3°F (218°±2°C) and testing flowability, the white thermoplastic shall have

a maximum percent residue of 22 percent and the yellow thermoplastic shall have a maximum residue of 24 percent.

(10) Reflectivity: The initial reflectance for the in-place marking shall have the minimum reflectance value of 450 mcd/lux/m² for white and 350 mcd/lux/m² for yellow when measured with a geometry of 1.5° observation angle and 86.5° entrance angle.

(11) Wet Reflectivity: The minimum in-place marking when wet shall have the minimum reflectance value of 200 mcd/lux/m² for white and 175 mcd/lux/m² for yellow when measured with a geometry of 1.5° observation angle and 86.5° entrance angle. The stripe shall be wet utilizing a pump type garden sprayer for 30 seconds. After 5 seconds, place the reflectometer on the stripe and measure the retro reflectance.

(12) Retained Reflectivity: The thermoplastic pavement marking material shall retain the minimum reflectance value of 130 mcd/lux/m² for at least four years after placement. Failure to meet this requirement shall require the contractor to replace the portion of the material shown to be below these minimums. The contractor shall supply a written warranty indicating the terms of this requirement.

(13) Inverted Profile: The thermoplastic pavement marking material shall be applied to have a individual profiles having a minimum height of 0.140 inches with the recessed inverted profiles having a thickness of 0.025 to 0.050 inches. The profiles shall be well defined and not excessively run back together.

1015.11 PREFORMED PLASTIC PAVEMENT MARKING TAPE:

(a) General: Preformed plastic pavement marking tape shall be approved products listed on QPL 64 and shall conform to ASTM D4505 Type I, Type I - High Performance (as specified below) or Type V, except as modified herein. The marking tape shall be Grade A, B, C, D, or E. The type and color shall be in accordance with the plans and the MUTCD.

(b) Thickness: All preformed plastic pavement marking tape shall have a minimum overall thickness of 1.5 mm when tested without the adhesive.

(c) Friction Resistance: The surface of the Type I preformed plastic pavement marking tape shall provide a minimum frictional resistance value of 35 British Polish Number (BPN) when tested according to ASTM E303. The surface of the Type I - High Performance and Type V preformed plastic pavement marking tape shall provide a minimum frictional resistance value of 45 British Polish Number (BPN) when tested according to ASTM E303 except values for the Type V are calculated by averaging values taken at downweb and at a 45° angle from downweb.

(d) Retroreflective Requirements: The preformed plastic pavement marking tape shall have the following minimum specific luminance values when measured in accordance with ASTM D 4061.

Type	Observation Angle	Entrance Angle	Specific Luminance mcd/m²/lx White	Yellow
I	0.2°	86°	500	400
	1.0°	86.5°	300	175
I - High Performance	0.2°	86°	700	560
	1.0°	86.5°	400	225

V	0.2°	86°	1100	800
	1.0°	86.5°	700	500

(e) Durability Requirements: The Type I High Performance preformed plastic pavement marking tape shall show no appreciable fading, lifting or shrinkage for a least 12 months after placement when placed in accordance with the manufacturer's recommended procedures on pavement surfaces having a daily traffic count not to exceed 15,000 ADT per lane.

The Type V preformed plastic pavement marking tape shall show no appreciable fading, lifting or shrinkage for a least 4 years after placement for longitudinal lines and at least 2 years after placement for symbols and legends.

The Type V preformed plastic pavement marking tape shall retain the following reflectance values for at least 4 years after placement for longitudinal lines and at least 2 years after placement for symbols and legends:

		Specific Luminance mcd/m²/lx	
Observation Angle	Entrance Angle	White	Yellow
1.0°	86.5°	100	100

(f) Plastic Pavement Marking Tape Guaranty (Type I High Performance and Type V): If the plastic pavement marking tape fails to conform to the performance and durability requirements of this subsection within 12 months for Type I High Performance and 4 years for Type V, the manufacturer shall replace the plastic pavement marking material at no cost to the Department.

1015.12 TRAFFIC PAINT. The contractor shall have the otion of furnishing either aklyd traffic paint or water-borne traffic paint; however, the same type paint shall be used throughout the project. Each paint container shall bear a label with the name and address of manufacturer, trade name or trade mark, type of paint, number of gallons, batch number and date of manufacture.

Paints shall be approved products listed in QPL 36, shall show no excessive settling, caking or increase in viscosity during 6 months of storage, and shall be readily stirred to a suitable consistency for standard spray gun application.

An infrared curve shall be generated in accordance with DOTD TR 610 and compared with the standard curve made during the initial qualification process.

(a) Alkyd Traffic Paint: This material shall be a rapid-setting compound suitable for use with hot application equipment. The material shall meet the following requirements:

Property	Test Method	Requirements Min.	Max.
Weight, lb/gal	ASTM D 1475	12.0	
Viscosity @ 25°C, Krebs Units	ASTM D 562	85	115
Dry to No Pick Up, s	ASTM D 711	---	180
Directional Reflectance, %	ASTM E 97		
White		80	
Yellow		50	
Bleeding	Fed. Spec. TT-P-115		Pass
Total Solids, % by weight	ASTM D 1644, Method A	70	
Film Shrinkage	[1]		Pass
Hiding Power	[2]		Pass
Pigment, %	ASTM D 2371	50	55
Nonvolatiles in Vehicle, % by wt	ASTM D 215	35	---
Flexibility	Fed. Spec. TT-P-1952		Pass
Pigment Composition	[3]		Pass

[1]Film Shrinkage: With a film applicator, cast a wet film with a thickness of 30 mils over a smooth glass plate. Allow sample to cure at room condition for 4 to 5 hours. Using a micrometer, measure the plate thickness before the film is cast using five measurements to obtain an average. The cured film shall have a minimum thickness of 12 mils.

[2]Hiding Power: The paint shall have a wet hiding power of at least 350 square feet per gallon. The compound shall have sufficient hiding power to cover any pavement when applied at a wet film thickness of 15 mils.

[3]Pigment Composition: White paint shall contain at least 1.5 pounds of titanium dioxide pigment per gallon as determined using DOTD TR 523 with at least 92 percent Ti02 content. The Ti02 shall conform to ASTM D 476. Yellow paint shall contain at least 1.3 pounds of medium chrome yellow pigment per gallon as determined using DOTD TR 523. Medium chrome yellow pigment shall conform to ASTM D 211, Type III.

(b) Water Borne Traffic Paint: This material shall be a rapid setting waterborne compound suitable for use with hot application equipment. The material shall meet the following requirements:

Property	Test Method	Requirements Min.	Max.
Weight, lb/gal	ASTM D 1475	12.0	

Viscosity, at 25°C Krebs Unit	ASTM D 562	75	90
Drying to No Pickup, min.	ASTM D 711	---	10
Dry through, min.	ASTM D 1640	---	20
Volume Solids	---	58	---
Total Solids, % by wt	ASTM D 2369	70	---
Pigment, % by wt	ASTM D 3723	45	55
Nonvolatile Vehicle, % by wt	Fed. Test 141B	40	---
Bleed Ratio	Fed. Spec. TT-P-1952	0.96	---
Daylight Reflectance, %	Fed. Test 141B		
White		85	---
Yellow		54	---
Hiding Power (Contrast Ratio) at 10 mils	Fed. Test 141B	0.96	---
Flexibility	Fed. Spec. TT-P-1952		Pass
Drying Time, min.	[1]	---	3
Fineness of Grind	ASTM D 1210	3	---
Freeze-Thaw	ASTM D 2243		Pass
Heat Stability	Fed. Spec. TT-P-1952		Pass
Color	[2]		Pass
Volatile Organic Compounds (g/L)	[3]	---	150
Pigment Composition			Pass

[1]Drying time to no track - Paint applied at 15 mils wet on the road surface with paint heated to 120-150°F shall not show tracking when a standard size automobile crosses in a passing maneuver at 3 minutes.

[2]Color - Yellow paint shall conform to the requirements of the following table when tested in accordance with ASTM E 1349. White shall be a clean, bright, untinted binder.

Color Specification Limits (Daytime)								
Color	1		2		3		4	
	x	y	x	y	x	y	x	y
Yellow	0.4756	0.4517	0.4985	0.4779	0.5222	0.4542	0.4919	0.4354

(The four pairs of chromaticity coordinates determine the acceptable color in terms of the CIE 1931 Standard Colorimetric System measured with Standard Illuminant C.)

[3]The white paint shall contain a minimum of 1.0 pound per gallon of titanium dioxide as determined using DOTD TR 523. The titanium dioxide shall conform ~~conforming~~ to ASTM D 476.

1015.13 GLASS BEADS FOR DROP-ON APPLICATION: Glass beads shall conform to AASHTO Designation: M247, Type I, with the following modifications:

Gradation of Glass Beads

Sieve Designation		
Standard, mm	Alternate No.	Mass Percent Passing
0.850	20	80-100
0.600	30	65-85
0.425	40	--
0.300	50	15-35
0.180	80	--
0.150	100	0-5

Section 732
Plastic Pavement Markings

732.01 DESCRIPTION. This work consists of furnishing and placing reflective pavement markings of hot applied thermoplastic or preformed cold applied plastic at the locations shown on the plans or as directed, in conformance with the MUTCD, plan details and these specifications.

732.02 MATERIALS.

(a) Thermoplastic Markings: Thermoplastic marking material shall be a plastic compound reflectorized by internal and external application of glass beads, conforming to Subsections 1015.10 and 1015.13, respectively. Width and color of markings shall be as specified.

Thermoplastic material shall be delivered in containers of sufficient strength to permit normal handling during shipment and transportation without loss of material. Approved heat-degradable containers that can be placed in heating kettles along with the plastic material will be permitted. Each container shall be clearly marked to indicate color of material, process batch number, name of manufacturer and date of manufacture. Glass beads used in drop-on application to molten plastic shall be shipped in sacks of multi-ply paper or burlap, both with a polyethylene liner. The sacks shall be strong enough to permit handling without damage, and have a capacity of 50 pounds of beads. Sacks shall be sufficiently water-resistant so that beads will not become wet or caked in transit.

(b) Preformed Plastic Markings: Preformed plastic markings shall conform to Subsection 1015.11.

732.03 CONSTRUCTION REQUIREMENTS.

(a) Equipment for Thermoplastic Markings: Material shall be applied to pavement by either spray or extrusion methods. Equipment shall provide continuous mixing and agitation of material. Conveying parts of equipment between main material reservoir and discharge mechanism shall prevent accumulation and clogging. Parts of equipment which come in contact with the material shall be easily accessible for cleaning and maintaining. Mixing and conveying parts shall maintain material at the application temperature. Equipment shall be capable of producing continuous uniformity in dimensions of stripes. Equipment shall be capable of producing various widths of traffic markings. Glass beads shall be applied to the molten surface of completed stripes by an automatic bead dispenser attached to the striping machine in such manner that beads are dispensed simultaneously with the thermoplastic material at a controlled rate of flow on installed lines. The glass bead dispenser shall be equipped with an automatic cutoff control synchronized with cutoff of thermoplastic material. Kettles to hold a minimum of 1,000 pounds of material shall be provided for melting and heating thermoplastic material. Kettles shall be equipped with automatic temperature control devices so that heating can be done by controlled heat transfer liquid

rather than direct flame, to provide positive temperature control and prevent overheating of material. Applicators and kettles shall be equipped and arranged to comply with requirements of the National Board of Fire Underwriters. Applicators shall be maneuverable to the extent that straight lines can be followed and normal curves can be made in a true arc. Applicator equipment shall consist of a motorized mobile unit capable of installing traffic stripes either left or right of applicating unit so that only one lane of traffic will be occupied during installation.

Applicators shall produce sharply defined lines and provide means for cleanly cutting off stripe ends and applying broken lines. The applicator unit shall have a tachometer or other approved device to insure uniform application at the required rate. It shall be adjustable for applying 1, 2, or 3 adjacent lines simultaneously at the specified spacing. The ribbon extrusion die or shaping die shall not be more than 2 inches above the roadway surface during application.

(b) Weather Limitations: Application of markings will not be permitted when there is excessive pavement moisture or when the surface temperature or ambient temperature is below 50°F. The pavement shall be considered excessively moist when it is visibly wet or when a 1 square foot piece of polyethylene film condenses moisture after being placed on the pavement surface for 15 minutes.

(c) Cleaning of Surfaces: Surfaces on which markings are to be applied shall be cleaned of materials that may reduce adhesion of the thermoplastic marking materials to the pavement. Cleaning shall be done by blast cleaning or grinding. Surfaces shall be kept clean until placement of markings.

Existing thermoplastic markings on the roadway that are not flaking or peeling do not require removal prior to placement of new thermoplastic markings. When thermoplastic markings will replace the existing painted markings, the existing painted markings do not require removal prior to applying new thermoplastic markings, provided the existing painted markings are not flaking or peeling.

Existing lane line pavement markings on bridges shall be removed prior to applying new markings.

When preformed plastic markings will replace any of the existing markings, the existing markings shall be removed prior to applying the preformed plastic markings.

Removal shall be accomplished by methods which will not damage the pavement or bridge deck. Removal shall be to such extent that 75 percent of the pavement surface or bridge deck under the markings is exposed. At the end of each day's operations, temporary pavement markings conforming to Section 713 shall be placed in areas where existing markings have been removed and new markings not placed. Temporary pavement markings shall be satisfactorily removed prior to resuming plastic striping operations.

(d) Application of Markings: Material shall be installed in specified widths from 4 inches to 24 inches. Finish lines shall have well defined edges and be free of waviness. Measurements shall be taken as an average through any 36-inch section of line. Longitudinal lines shall be offset approximately 2 inches from longitudinal joints. A tolerance of +1/2 inch and -1/8 inch from the specified width will be allowed, provided the variation is gradual. Segments shall square off at each end without mist or drip. Transverse variations from the control device up to 1 inch will be allowed provided the variation does not increase or

decrease at the rate of more than 1/2 inch in 25 feet. Lines not meeting these tolerances shall be removed and replaced at no direct pay.

(1) Thermoplastic Markings: Thickness of material, not including drop-on beads, shall be not less than 90 mils for lane lines, edge lines and gore markings and not less than 125 mils for crosswalks, stop lines, and word and symbol markings. A binder-sealer material recommended by the thermoplastic marking manufacturer shall be applied to the portland cement concrete pavement surface or bridge deck prior to application of the thermoplastic markings. Thermoplastic material shall be applied either by extrusion at 390°F to 450°F or by spray at 410°F to 450°F. Immediately after application of the markings, glass beads shall be applied at a minimum rate of 300 pounds per mile. Material shall not scorch or discolor when kept at this temperature range for 4 hours.

(2) Preformed Plastic Markings: Plastic material shall be applied by removing release paper and applying adequate pressure to ensure proper adhesion. Material not adhering properly shall be satisfactorily corrected at no direct pay.

732.04 MEASUREMENT.

(a) Plastic Pavement Striping: Plastic striping will be measured by the linear foot or mile, as specified.

(1) Linear Foot: Measurement will be made by the linear foot of striping, exclusive of gaps.

(2) Mile: Measurement will be made by the mile of single stripe per roadway. No deduction will be made for standard 30-foot design gaps in broken-line striping; however, deductions will be made for the length of other gaps or omitted sections.

(b) Plastic Pavement Legends and Symbols: Plastic legends and symbols will be measured per each legend or symbol. Symbols shall include all letters, lines, bars or markings necessary to convey the message at each location.

(c) Removal of Existing Markings: Removal of existing markings will be measured by the mile and will include removal of lane lines, edge lines, gore markings, symbols and raised traffic markings for the full roadway and shoulder width.

732.05 PAYMENT. Payment for plastic pavement markings and removal of existing markings will be made at the contract unit prices under:

Item No.	Pay Item	Pay Unit
732(01)	Plastic Pavement Striping (__" Width)	Linear Foot
732(02)	Plastic Pavement Striping (Solid Line) (___" Width)	Mile
732(03)	Plastic Pavement Striping (Broken Line) (__" Width)	Mile
732(04)	Plastic Pavement Legends and Symbols (Type)	Each
732(05)	Removal of Existing Markings	Mile

Appendix-C Interdepartment correspondence of Georgia DOT

KENT

G.O.T. 66

DEPARTMENT OF TRANSPORTATION
STATE OF GEORGIA

INTERDEPARTMENT CORRESPONDENCE

FILE

OFFICE Forest Park, Ga

DATE January 15, 1999

FROM Kent L. Sager, Maintenance Activities Unit Engineer

TO Stephen T. Henry, State Maintenance Engineer

SUBJECT Selection of Type PB Permanent Tape for Use on Concrete Surfaces

This office has reviewed and used Type PB Permanent Tape in various small experimental sections. Also, the construction office has used this product on both the I75/I85 HOV Lane Project (on bridge decks), and small supplemental agreements on bridge decks in various projects. Following is a list of locations where this product has been used:

- Fly Over Bridge I75 South to I285 East inside edgeline – Placed 10/17/91. This was the first location and was picked due to the crossing traffic on this line. This location has done excellent under the abuse condition that exists and is almost (8) years old.
- I-675 Southbound Skipline – Placed August 1992. This was the second location placed. This location has done excellent while we have restriped all other lines at least (2) times and in some areas (3) times.
- Numerous bridge decks throughout the state have had this product placed on them with maintenance forces between the summer of 1993 and the summer of 1995. These locations have proven to hold the line while we would not be able to maintain thermoplastic on them.
- Tom Moreland Interchange – This was done under a wet weather project funded by FHWA. This interchange has had some notable problems which cannot be denied, however, this does not appear indicative of the products use overall.
- I-20 HOV Lane Stripes – Placed by maintenance in November 1994, this section has had a few problem areas which I believe should be attributed to the weather conditions (time of year) of placement. We were quite frankly rushed to open the HOV Lanes prior to the new year.
- SR 316 from Gwinnett County to Athens. This section was placed using contrast skiplines in late 1995 and early 1996. This section has done quite

well while most of the thermoplastic edgelines are deteriorated and require replacing.

In addition to these, the I75/I85 contrast markings on bridge decks have performed extremely well over the last two years. I have no doubt that there would be no thermoplastic remaining on these bridge decks if the tape had not been used.

It is obvious from our experience that application according to the manufacturers recommendation is a must with the tape. However, where the guidelines have been followed explicitly, there seems to be great success with the product.

I don't believe the importance of contrasting markings on concrete can be understated. From my overall review of our concrete sections, it becomes apparent that even non-contrasting tape will easily blend with concrete color just as our thermoplastic will. The contrast markings are a tremendous improvement both on the SR316 and I75/I85 projects.

In 1995, we were looking at placing contrast tape on sections of I-16 in middle Georgia. I did a cost analysis (attached) which was to show life cycle cost comparisons between contrast tape and contrast thermoplastic usage. Based on a (6) year life of the tape, this comparison showed the tape to be more cost effective. This comparison used a full 10' black thermoplastic line placed before each 10' white thermoplastic line. It also included the need to eradicate and place both products (1) time with eradication and placement of thermoplastic every (2) years thereafter. The tape product is contrasted on each side and should be seen as equivalent to the way thermoplastic would be contrasted even though the same method is not used for each.

The laboratory also did a life cycle cost analysis (attached), however, contrasting was not considered, and eradication was only performed on thermoplastic the first time rather than each subsequent time. Since eradication will approach $0.50 per foot it is important to consider this. Please see the attached e-mail from Don Wishon regarding removal costs not being part of the cost analysis. Don states that over their (8) year life considered, this would show the tape to be more cost effective.

I performed a (6) year life cycle, the lab performed a (8) year life cycle, but where this product has been placed should provide at least (8) years if not (10) years of service. I would place the break-even point at approximately (5) to (6) years, which is equivalent to our life expectancy of thermoplastic on asphalt. We have proven time and time again that we are not getting (2) years out of thermoplastic on concrete. For example, we have striped I285 concrete (3) times in the last (5) years – 1993 under contract, 1995 with maintenance, and 1998 under contract. The same is true of most all other concrete sections we maintain.

I have also attached for your review, reports from both the Texas NTPEP test deck and the Pennsylvania NTPEP test deck on pavement markings. This testing uses transverse markings and measure reflectivity in the wheel paths. Both reports attached are where measurements were taken on PCC pavements. Although you will see differing values, the trend is indicative of what we see in Georgia. The tape is quite high with initial readings over 800 and as high as 2000 with readings of 500 to 800 at (2) years. Thermoplastic usually starts out around 600 and is down to 100 to 200 by the end of (2) years. Needless to say, at (2) years the tape is as high as most initial thermoplastic readings. Higher readings make a great deal of difference when viewing against concrete color. The higher the reading, the less blend with concrete. It does not make as much difference with asphalts due to the contrast between the white and the asphalt.

With all of this said, I think it is extremely important that we consider the maintenance schedule of the pavement itself. We should not consider using a tape product where we expect to perform maintenance or full reconstruction within less than the five-year period. Pavements should be selected with the range of minimum pavement maintenance within the five-year period. This is certainly true of the sections which we have used tape on to date. If we can't approach the break-even point, we are expending additional funds unnecessarily. I would not suggest the use of tape on most of our asphalts since we can expect thermoplastic to provide (5) years and may perform much more maintenance on these sections.

Our thermoplastic program is very successful, and with the exception of concrete surfaces there is no reason to even think about alternative materials being used. However, tape usage on selected concrete pavements provides incentives beyond just better life cycle cost. The following gains can also be attributed to tape on concrete:

- Less public exposure to moving operations due to longer life cycles
- Less DOT employee exposure to traffic which is in majority urban areas
- Increased stability and reflectivity of lines
- Better wet weather reflectivity due to Tape Design
- Less environmental concern due to less eradication of thermoplastic
- Life cycle will mimic that of thermoplastic on asphalt
- More aesthetically pleasing to the public due to much less section loss
- Use of competitive marking materials for cost containment

I am sure other benefits can be attributed, but if we are not in the public way just one time we have benefited greatly. The reduced cycle on particular concrete sections allows my crews to handle the additions in lane miles over the past several years without stretching resources. This office has also promoted and will continue to strongly promote use of contractor services in providing the level service that the public deserves in pavement markings. Along with this, it is important to note that when we discuss concrete sections in general, these are

areas where crews and the public are both submitted to higher accident rates with mobile work crews.

With thermoplastic mean cost running between $0.15 per foot and $0.75 per foot, I would expect a productive project to average around $0.25 per foot including gore lines and ramps. Adding the cost of eradication should add approximately $0.50 per foot with a combined cost of thermoplastic placement at $0.75 per foot not considering contrasting. I expect tape to be placed between $3.00 and $4.50 per foot including contrasting skip lines, eradicating, and placing gore and ramp lines. I think the products are cost comparable at the (5) to (6) year timeframe and provide added benefit which costs cannot be directly calculated for.

I have scheduled time with the lab and my office to take reflectivity readings and subjective surveys of several of the tape sections identified. This will be done on Wednesday and Thursday of next week. I will forward this information to you when we have compiled it.

If you have any questions on this, please let me know.

kls
attachments
Cc file
Don Wishon
Larry Seabrook
Steve Parks

Attachments

A. Thermoplastic versus Tape Contrast Cost Comparison MAU 1995
B. Thermoplastic versus Tape Cost Comparison GDOT Lab 1995
C. Don Wishon E-mail on Lab Cost Compasrison
D. Pennsylvania NTPEP Test Deck Values on Concrete Report98-NTPEP142
E. Texas NTPEP Test Deck Values on Concrete Report98-NTPEP141

Thermoplastic versus Permanent Tape Cost Comparison
Contrast Markings on Concrete Pavements

The cost comparison is based on a (2) year usable life with thermoplastic markings on concrete and a (6) year usable life with Permanent Tape (GA Type PB).

$486.56 per mile - March 1995 Mean Contract Cost - White Thermoplastic Skipline
$583.87 per mile - *Estimated Contract Cost - Black Thermoplastic Skipline
$514.80 per mile - March 1995 Mean Contract Cost - Thermoplastic Skipline Eradication

---

$1,585.23 per mile - Total Contract Thermoplastic Cost

$4,224.00 per mile - **Estimated Contract Cost - Contrast White/Black Permanent Tape
$514.80 per mile - March 1995 Mean Contract Cost - Thermoplastic Skipline Eradication

---

$4,738.80 per mile - Total Contract Permanent Tape Cost

Life Cycle Comparison

$1,585.23 per mile - Thermo Cycle (1)	$4,738.80 per mile - Permanent Tape Cycle (1)
$1,632.79 per mile - Thermo Cycle (2)***	
$1,681.77 per mile - Thermo Cycle (3)***	
$4,899.79 per mile - Thermo (6) year cost	**$4,738.80 per mile - Tape (6) year cost**

Cost Savings using Tape = $161.00 per Skipline Mile

* Black Thermoplastic estimate is based on 20% increase over White Thermoplastic 20% is the quoted increased cost of material due to the pigments in Black Thermo.

** Tape is estimated to cost $3.20 per foot for total installation. With 1320 L.F. in a Skipline mile = $4,224.00 per mile. Cost of material only is approximately $2.80 per linear foot.

*** Cycles (2) and (3) of Thermoplastic Installation are based on recurring 3.0% annual inflation rate.

Other benefits of using Permanent Tape Markings in specified areas

Less public exposure to work zones due to increased Life Cycle of Markings
Less D.O.T. employee exposure to areas in which Tape Markings are Placed
No loss of marking lines as with Thermoplastic on Concrete
Increased and stable reflectivity of marking lines
Better wet weather reflectivity due to Tape Design
Less environmental concerns due to loss of Thermoplastic or removal of Thermoplastic
Tape Life Cycle will mimic that of Thermoplastic placed on Asphalt Surfaces
Compiled 5/18/95 - M.A.U.

(A)

DEPARTMENT OF TRANSPORTATION

STATE OF GEORGIA

INTERDEPARTMENT CORRESPONDENCE

FILE

OFFICE Materials and Research
Forest Park, Georgia
DATE July 11, 1995

FROM Ronald Collins, State Materials and Research Engineer

TO Steve Parks, Director of Operations

SUBJECT **I-16 THERMOPLASTIC SURVEY**

Attached is a summary of retroreflectivity measurements and visual inspection data for thermoplastic striping on I-16.

Between June and September of 1993, the entire length of I-16 was restriped in both directions. Retroreflectivity was measured on these restripes in millicandelas/lux/m2 with a Mirolux instrument. For the yellow edgeline, Mirolux readings ranged from 82 to 339 with an average of 162, and for the white edgeline, the readings ranged from 78 to 516 with an average of 258. The readings on the white skipline ranged from 91 to 417 with an average of 248.

In general, sufficient beads remain to provide adequate retroreflectivity, but the visual appearance of the stripe was very poor. Since there had been no removal of existing traffic marking, virtually all striping consists of more than one layer of thermoplastic. In several locations where the old layer bonded poorly to the concrete pavement, flaking has occurred, causing the new stripe layer to delaminate along with the old layer underneath.

There are two types of striping material that may be utilized to replace the existing traffic markings. These two materials are thermoplastic and Type PB permanent tape. We performed life cycle cost analysis on both types of striping materials. The results of these analyses are as follows:

<u>General Information</u>:

Item	Cost
Permanent Tape (PB)	$.90/ft (includes installation cost)
Thermoplastic	$.13/ft (includes installation cost)
Traffic Marking Removal	$.20/ft

B.1

Analysis Period = 16 years Differential Discount Rate = 3%

Permanent Tape (PB) (Service Life) = 8 years
Thermoplastic (Service Life) = 2 years

Traffic marking removal cost was added to the initial cost and to the eight year rehabilitation cost of both materials.

Annualized Cost Results:

Item	Annualized Cost
Permanent Tape (PB)	$827/mile
Thermoplastic	$509/mile

Based on the results of the thermoplastic survey and the life cycle cost analyses, this office recommends that the existing thermoplastic on I-16 be removed by means of sandblasting, shot blasting, mechanical abrasion, or high pressure water blasting and that a hydrocarbon thermoplastic striping material be utilized to restripe I-16. The residue from the removal of the yellow thermoplastic may require containment, and testing for leachable lead and chromium content by TCLP. If the residue is determined to be a hazardous waste, it must be properly treated before disposal. Type PB permanent tape could be considered for restriping utilization, if its material and installation cost was lowered to approximately $.48/foot or the expected life of this material could be proven to be longer then our estimate of 8 years.

Black contrast markings, which may be either non-reflective paint or thermoplastic, should also be installed to improve driver recognition of skiplines during daylight hours. It should also be noted that the new stripes may be located on the asphaltic concrete shoulders.

If you require further information, please contact Don Wishon at 363-7560.

PK:

B2

Sager, Kent

From: Wishon, Donald
Sent: Friday, January 15, 1999 3:55 PM
To: Sager, Kent
Subject: Type PB permanent tape vs. thermoplastic

I looked back over the I-16 thermoplastic survey that was done in 1995. I noticed that removal costs were for the initial installation and at eight years for both materials. Our current specification requires the complete removal of the old thermoplastic prior to the next installation. Being the case, the thermoplastic price should have included six more removals. This should have raised the annualized cost above that of the tape.

I looked at the Type PB installation on SR 316 last week on my way to Athens. This installation has about four years of exposure at this time. The black contrast edge does offer advantages with visibility, especially during the day. With proper installation, there is no reason why this material won't last at least eight years. Some other areas, i.e., Moreland Interchange, I-20 and bridges on I-75 appear to be functioning very well at this time.

Pam will be available to go with Grady on Wednesday, January 20, 1999, to survey SR 316 and the other locations.

Please let me know if I can be of further assistance.

Don

C

Table 4

Rte-220
(Portland Concrete Cement)

Retroreflectivity and Durability
Pennsylvania

Code	Product Id number	Color	Comp	NOV'97 RR	NOV'97 DUR	MAY'98 RR	MAY'98 DUR	JUNE'98 RR	JUNE'98 DUR	JULY'98 RR	JULY'98 DUR
STR-96-11-PA	TM8209(yellow)	Y	BSW	262	10	242	10	249	9	243	9
				99	8	70	6	65	5	62	5
STR-96-2-PA	Epoplex LS52(yellow)	Y	EPO	172	6	64	4	81	3	52	3
				37	4	14	2	16	2	12	1
STR-96-212	MARK 55.2NV (yellow)	Y	PCB	203	10	192	10	190	10	184	10
				88	9	61	9	57	8	50	8
STR-96-213	MARK 55.2NV (yellow)-nonlead	Y	PCB	253	10	242	10	258	10	249	10
				99	9	55	8	56	8	50	8
	TAPE-PERMANENT-(WHITE)										
STR-96-158-PA	3M Stamark 330 (white)	W	3M	310	10	266	10	261	10	253	10
				75	9	54	8	54	8	44	8
STR-96-158-PA	3M Stamark 340 (white)	W	3M	245	10	225	10	217	10	195	10
				91	10	63	9	69	9	58	9
STR-96-160-PA	3M Stamark 380I (white)	W	3M	652	10	467	10	471	10	495	10
				119	10	104	9	118	9	99	9
STR-96-176-PA	ATM 300W 19-302 (white)	W	ATM	139	10	103	9	97	9	90	9
				55	10	50	7	54	7	47	7
STR-96-176-PA	ATM 400W 19-402 (white)	W	ATM	260	10	155	10	149	10	132	10
				60	10	57	10	63	9	60	9
STR-96-135-PA	deltaline XRP (white)	W	BL	391	10	284	10	293	10	274	10
				101	10	83	10	101	9	93	9

3M STAMARK 380I
PLACED 1996

Table 4

Rte-220
(Portland Concrete Cement)

Retroreflectivity and Durability
Pennsylvania

Code	Product Id number	Color	Comp	NOV'97 RR	NOV'97 DUR	MAY'98 RR	MAY'98 DUR	JUNE'98 RR	JUNE'98 DUR	JULY'98 RR	JULY'98 DUR
STR-98-6-PA	TM1104(white)	W	BSW	85	5	10	1	18	1	23	1
				112	7	10	2	55	2	35	1
STR-98-47-PA	T2000WGE200H(white)	W	CAT	121	7	24	1	24	1	20	1
				128	9	46	1	25	1	30	1
STR-98-50-PA	T2000WGE200A(white)	W	CAT	379	10	379	9	397	9	407	8
				159	9	142	8	158	8	147	8
STR-98-53-PA	T5000WGE500A(white)	W	CAT	390	10	295	7	300	6	287	6
				237	9	21	1	23	1	10	1
STR-98-56-PA	T7000WGS701H(white)	W	CAT	188	9	159	8	129	7	129	7
				17	1	20	1	0	0	20	0
STR-98-59-PA	T7000WGS701A(white)	W	CAT	131	7	66	3	70	3	61	3
				19	0	10	0	0	0	0	0
STR-98-62-PA	T2000YGE240A(white)	W	CAT	393	10	384	8	384	8	390	8
				150	9	122	6	122	5	106	5
STR-98-186-PA	Tuffline 15WAX-BADA (white)	W	CRW	212	10	124	4	118	4	107	3
				136	9	99	5	96	5	81	5
STR-98-188-PA	TuffTape TT-WTX-BADA(white)	W	CRW	326	10	195	8	198	7	205	7
				122	10	101	9	123	9	105	9
STR-98-124-PA	Premark Standard (white)	W	FTI	152	6	30	2	29	2	26	2
				144	9	134	8	139	8	125	7
STR-98-125-PA	Premark 20/20 Flex (white)	W	FTI	96	5	69	4	71	4	65	4
				101	8	68	7	84	6	72	6

CROWNTECH THERMO
PLACED 1996

D2

El Paso, Texas
LTL 2000

TABLE 9

Concrete Deck

Product Number	Reflectivity Data		
	Oct 1997	Feb 1998	June 1998
89	340	228	270
	412	367	366
90	518	437	438
	573	507	535
91	380	301	320
	421	409	435
101	224	179	148
	295	286	236
102	137	111	133
	185	137	141
103	399	525	267
	379	511	334
104	291	255	337
	340	330	398
107	412	332	191
	471	429	424
108	196	187	147
	204	182	175
109	363	398	325
	421	340	349
110	249	229	229
	294	231	260
111	891	864	856
	895	977	919
112	648	584	594
	624	660	639
113	326	272	264
	374	357	379
114	240	173	200
	217	256	256

CONCRETE

3M STAMARK 380 WHITE

3M STAMARK 381 YELLOW

PLACED 6/19/96

MS Excel filename:
2refc.xls

(E,)

El Paso, Texas
LTL 2000

TABLE 9

Concrete Deck

Product Numbers	Reflectivity Data		
	Oct 1997	Feb 1998	June 1998
121	652	620	582
	737	704	531
122	556	508	534
	574	554	563
129	435	386	408
	428	455	475
130	445	318	304
	390	419	444
131	450	334	330
	533	394	413
132	222	185	210
	277	238	246
133	137	166	131
	254	143	107
134	91	93	146
	184	87	123
135	525	446	440
	494	490	524
136	197	165	178
	225	206	219

CONCRETE

STIMSONITE THERMO ALKYD WHITE

STIMSONITE THERMO ALKYD YELLOW

PLACED 6/12/96

MS Excel filename:
2refc.xls

(E2)

Appendix-D Other test results

AN INVESTIGATION INTO APPLICATION ON BONDING STRENGTHS OF THERMOPLASTIC MARKING ON CONCRETE AND ASPHALTIC ROADWAY SURFACES

Installation Date:	October 13,1999
Type of Pavement:	Concrete and Asphalt
Location of Installation:	STUART, (SR 714, near FDOT Turnpike)
Location Condition at application:	Good
Marking Material:	W5G-5GX-FF (Stimsonite)
Batch No./ Lot No.	9179952
Temperature of Application:	405^0F
Air Temperature:	87^0F
Time of Application:	10:30 AM
Humidity:	34^0F
Pavement Temperature:	100^0F
Dry Thickness:	90 mils
Reflective Sphere Manufacturer:	Flex-O-Lite, Inc.
Glass Sphere Lot Number:	9189952
Primer for Concrete:	Briteline, Contact Ahhesive UN 1133 (one-part) C_{20} Batch No. 9237

AN INVESTIGATION INTO APPLICATION AND BONDING STRENGTHS OF THERMOPLASTIC MARKING ON CONCRET AND ASPHALTIC ROADWAY SURFACES

Date Tested: October 22,1999

RETROREFLECTIVITY ON CONCRETE

LTL 2000 (MCD/LUX/M2)	MEASUREMENT 1	MEASUREMENT 2	MEASUREMENT 3	AVERAGE	TEST RESULTS
1. Waterblasting	214	184	164	187	Failed
2. Grinding	128	74	77	93	Failed
3. Sandblasting	122	118	132	124	Failed
4. Wire Blasting	197	200	189	195	Failed
5. No Surface Preparation	200	151	136	162	Failed

MIROLUX 15 (MCD/LUX/M2)	MEASUREMENT 1	MEASUREMENT 2	MEASUREMENT 3	AVERAGE	TEST RESULTS
1. Waterblasting	248	213	239	233	Failed
2.Grinding	294	276	240	270	Failed
3 Sandblasting	257	215	218	230	Failed
4. Wire Brushing	319	279	281	293	Failed
5. No Surface Preparation	274	258	194	242	Failed

AN INVESTIGATION INTO APPLICATION AND BONDING STRENGTHS OF THERMOPLASTIC MARKING ON CONCRET AND ASPHALTIC ROADWAY SURFACES

RETROREFLECTIVITY ON ASPHALT

LTL 2000 (MCD/LUX/M2)	Measurement 1	Measurement 2	MEASUREMENT 3	AVERAGE	TEST RESULTS
1. Waterblasting	79	99	101	93	Failed
2. Grinding	242	213	196	223	Failed
3. Sandblasting	178	212	245	212	Failed
4. Wire Blasting	257	271	264	264	Passed
5. No Surface Preparation	205	195	218	206	Failed
6.On top of existing thermo	187	129	99	138	Failed

MIROLUX 15 (MCD/LUX/M2)	MEASUREMENT 1	MEASUREMENT 2	MEASUREMENT 3	AVERAGE	TEST RESULTS
1. Waterblasting	173	193	173	180	Failed
2.Grinding	307	327	312	315	Passed
3 Sandblasting	349	314	324	329	Passed
4 Wire Brushing	382	362	351	365	Passed
5. No Surface Preparation	398	312	276	329	Passed
6. On top of existing thermo	153	206	306	222	Failed

LAB No. 29842 -C MATERIAL GLASS SPHERES SAMPLE JB0001

Received 10/20/99 Reported By J. Benhaim

Thermo Research Study

Passing Sieve		%	%Round		Sieve %	% round
					97.18	
#No. 20	50.13	100	~~100~~	—	100	—
#No. 30	44.10	88	~~88~~	63	92	64
#No. 50	9.45	19	~~21~~	78	29	78
#No. 100	0	0	~~0~~	66	0.4	67
Overall Roundness		69				70
Moisture Resistance		Sat				
Sharp, Milkiness, Angular Particles		Sat				
Scratching		Sat				
Foreign Material		Sat				
Index of Refraction		Sat				

This Sample _____ Specifications for Glass Spheres, Type I

Pass Type I

#

Tested By: LL

Date: 11-12-99

FORM 694-01
1-70

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

MISCELLANEOUS TEST REPORT

JOB NO.	ROAD	DISTRICT
1909701A101	N/A	N/A

Material: Thermoplastic (White)

Contract Number: N/A

Quantity Represented: N/A

Producer: Stimsonite Corp.

Source of Supply: N/A

Submitted By: J. Benham

Intended Use: N/A

Sampled By: N/A

Sampled From: N/A

Date Sampled: 10/25/99

Date Received: 10/25/99

Date Tested: N/A

Date Reported: 12/07/99

Lab No.: 29865C TEST RESULTS Sample No.: WB0001

Batch # White - W5G-5GX-FF
BAG SAMPLE

Glass Spheres	38
True Sphere	82
Softening Point	100° F
% TiO^2	N/A

NOTE: QPL Evaluation

This sample **FAILED** specifications for white thermoplastic materials. Deficient 2% Glass Spheres.
Note: Pass/Fail status to be determined by the evaluator, this is the reporting of test data only.

CC: J. Benham
Chem Lab:SMO

Tested By: Maxie Hicks

State Materials Engineer

FORM 694-01
1-70

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
MISCELLANEOUS TEST REPORT

JOB NO.	ROAD	DISTRICT
1909701A101	N/A	N/A

Material: Thermoplastic (White)

Contract Number: N/A

Quantity Represented: N/A

Producer: Stimsonite Corp.

Source of Supply: N/A

Submitted By: J. Benham

Intended Use: N/A

Sampled By: N/A

Sampled From: N/A

Date Sampled: 10/25/99

Date Received: 10/25/99

Date Tested: N/A

Date Reported: 12/07/99

Lab No.: 29866C TEST RESULTS Sample No.: W0003

Batch # White - W5G-5GX-FF
#1 CAN SAMPLE

Glass Spheres	20
True Sphere	84
Softening Point	106° F
% TiO^2	N/A

NOTE: QPL Evaluation

This sample **FAILED** specifications for white thermoplastic materials. Deficient 20% Glass Spheres.
Note: Pass/Fail status to be determined by the evaluator, this is the reporting of test data only.

CC: J. Benham
Chem Lab:SMO

Tested By: Maxie Hicks

State Materials Engineer

FORM 694-01
1-70

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
MISCELLANEOUS TEST REPORT

JOB NO.	ROAD	DISTRICT
1909701A101	N/A	N/A

Material: Thermoplastic (White)

Contract Number: N/A

Quantity Represented: N/A

Producer: Stimsonite Corp.

Source of Supply: N/A

Submitted By: J. Benham

Intended Use: N/A

Sampled By: N/A

Sampled From: N/A

Date Sampled: 10/25/99

Date Received: 10/25/99

Date Tested: N/A

Date Reported: 12/07/99

Lab No.: 29866C — TEST RESULTS — Sample No.: W0003

Batch # White - W5G-5GX-FF
#2 CAN SAMPLE

Glass Spheres	33
True Sphere	90
Softening Point	106° F
% TiO^2	N/A

NOTE: QPL Evaluation

This sample **FAILED** specifications for white thermoplastic materials. Deficient 7% Glass Spheres.
Note: Pass/Fail status to be determined by the evaluator, this is the reporting of test data only.

CC: J. Benham
Chem Lab:SMO

Tested By: Maxie Hicks

State Materials Engineer

FORM 699-01
1-70

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
MISCELLANEOUS TEST REPORT

JOB NO.	ROAD	DISTRICT
1909701A101	N/A	N/A

Material: Thermoplastic (White)

Contract Number: N/A

Quantity Represented: N/A

Producer: Stimsonite Corp.

Source of Supply: N/A

Submitted By: J. Benham

Intended Use: N/A

Sampled By: N/A

Sampled From: N/A

Date Sampled: 10/25/99

Date Received: 10/25/99

Date Tested: N/A

Date Reported: 12/07/99

Lab No.: 29867C TEST RESULTS Sample No.: W0004

Batch # White - W5G-5GX-FF
#2 CAN SAMPLE

Glass Spheres	39
True Sphere	89
Softening Point	106° F
% TiO^2	N/A

NOTE: QPL Evaluation

This sample **FAILED** specifications for white thermoplastic materials. Deficient 1% Glass Spheres.
Note: Pass/Fail status to be determined by the evaluator, this is the reporting of test data only.

CC: J. Benham
Chem Lab:SMO

Tested By: Maxie Hicks

State Materials Engineer

FORM 694-01
1-70

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
MISCELLANEOUS TEST REPORT

JOB NO.	ROAD	DISTRICT
1909701A101	N/A	N/A

Material: Thermoplastic (White)

Contract Number: N/A

Quantity Represented: N/A

Producer: Stimsonite Corp.

Source of Supply: N/A

Submitted By: J. Benham

Intended Use: N/A

Sampled By: N/A

Sampled From: N/A

Date Sampled: 10/25/99

Date Received: 10/25/99

Date Tested: N/A

Date Reported: 12/07/99

Lab No.: 29867C TEST RESULTS Sample No.: W0004

Batch # White - W5G-5GX-FF
#1 CAN SAMPLE

Glass Spheres	32
True Sphere	82
Softening Point	105° F
% TiO^2	N/A

NOTE: QPL Evaluation

This sample **FAILED** specifications for white thermoplastic materials. Deficient 8% Glass Spheres.
Note: Pass/Fail status to be determined by the evaluator, this is the reporting of test data only.

CC: J. Benham
Chem Lab:SMO

Tested By: Maxie Hicks

State Materials Engineer

FORM 694-01
1-70

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
MISCELLANEOUS TEST REPORT

JOB NO.	ROAD	DISTRICT
1909701A101	N/A	N/A

Material: Thermoplastic (White)

Contract Number: N/A

Quantity Represented: N/A

Producer: LaFarge Roadmarking

Source of Supply: Georgia

Submitted By: J. Benham

Intended Use: N/A

Sampled By: N/A

Sampled From: N/A

Date Sampled: 08/22/99

Date Received: 08/23/99

Date Tested: 11/10/99

Date Reported: 12/07/99

Lab No.: 29515C TEST RESULTS Sample No.: W0001

Batch # White - N/A
Lot # N/A

Glass Spheres	34
True Sphere	73
Softening Point	105° F
% TiO^2	13.7%

NOTE: QPL Evaluation

This sample **FAILED** specifications for white thermoplastic materials. Deficient 1% Glass Spheres.
Note: Pass/Fail status to be determined by the evaluator, this is the reporting of test data only.

CC: J. Benham
Chem Lab:SMO

Tested By: Maxie Hicks

State Materials Engineer

FDOT/SMO
Chemical Laboratory
TiO_2 & Pb Quality Control Report

Date 12 / 8 / 99

The following results of TiO_2 and elemental Pb are obtained by using the ICAP instrument. The two SOPs used for samples preparation are listed below.

1. Analysis of Thermoplastic Pavement Marking Material for Organic Matter and Titanium Dioxide.
2. Lead in Paint by Hotplate or Microwave based acid digestion for Atomic Absorption or ICAP.

Laboratory Number	Vendor	Color	TiO_2 %/weight	Pb %/weight	
1. 29865-Yock	—	W	10.2	—	PASS
2. 29865-BAS	—	W	11.6	—	PASS
3. 29866-1	—	W	10.7	—	PASS
4. 29866-2	—	W	10.6	—	PASS
5. 29867-1	-	W	9.93	—	FAIL
6. 29867-2	-	W	8.51	—	FAIL
7. 29811	—	W	10.6	—	PASS

FDOT/SMO
Chemical Laboratory
TiO_2 & Pb Quality Control Report

Date 12 18 199

The following results of TiO_2 and elemental Pb are obtained by using the ICAP instrument. The two SOPs used for samples preparation are listed below.

1. Analysis of Thermoplastic Pavement Marking Material for Organic Matter and Titanium Dioxide.
2. Lead in Paint by Hotplate or Microwave based acid digestion for Atomic Absorption or ICAP.

Laboratory Number	Vendor	Color	TiO_2 %/weight	Pb %/weight
1. 29875	–	W	14.0	– PASS
2. 29880	–	W	12.3	– PASS
3.				
4.				
5.	M. Stot			
6.	12/8/99			
7.				

Rl: 205 mcd·m^{-2}·lx^{-1}
Rt: 360 1999 Oct 22 13:45:13 Status: 0

Rl: 195 mcd·m^{-2}·lx^{-1}
Rt: 361 1999 Oct 22 13:46:09 Status: 0

Rl: 218 mcd·m^{-2}·lx^{-1}
Rt: 362 1999 Oct 22 13:46:54 Status: 0

Rl: 178 mcd·m^{-2}·lx^{-1}
Rt: 363 1999 Oct 22 13:58:57 Status: 0

Rl: 212 mcd·m^{-2}·lx^{-1}
Rt: 364 1999 Oct 22 13:59:56 Status: 0

Rl: 245 mcd·m^{-2}·lx^{-1}
Rt: 366 1999 Oct 22 14:00:31 Status: 0

Rl: 271 mcd·m^{-2}·lx^{-1}
Rt: 368 1999 Oct 22 14:13:18 Status: 0

Rl: 257 mcd·m^{-2}·lx^{-1}
Rt: 369 1999 Oct 22 14:13:44 Status: 0

Rl: 264 mcd·m^{-2}·lx^{-1}
Rt: 370 1999 Oct 22 14:14:08 Status: 0

Rl: 242 mcd·m^{-2}·lx^{-1}
Rt: 371 1999 Oct 22 14:14:39 Status: 0

Rl: 231 mcd·m^{-2}·lx^{-1}
Rt: 372 1999 Oct 22 14:14:54 Status: 0

Rl: 196 mcd·m^{-2}·lx^{-1}
Rt: 373 1999 Oct 22 14:15:12 Status: 0

Rl: 79 mcd·m^{-2}·lx^{-1}
Rt: 374 1999 Oct 22 14:21:09 Status: 2

Rl: 99 mcd·m^{-2}·lx^{-1}
Rt: 375 1999 Oct 22 14:21:39 Status: 0

Rl: 181 mcd·m^{-2}·lx^{-1}
Rt: 376 1999 Oct 22 14:21:56 Status: 0

Rl: 187 mcd·m^{-2}·lx^{-1}
Rt: 377 1999 Oct 22 14:26:09 Status: 0

Rl: 129 mcd·m^{-2}·lx^{-1}
Rt: 378 1999 Oct 22 14:26:36 Status: 0

Rl: 99 mcd·m^{-2}·lx^{-1}
Rt: 379 1999 Oct 22 14:26:51 Status: 0

Rl: 208 mcd·m^{-2}·lx^{-1}
Rt: 380 1999 Oct 22 14:56:14 Status: 0

Rl: 208 mcd·m^{-2}·lx^{-1}
Rt: 380 1999 Oct 22 14:56:14 Status: 0

Rl: 151 mcd·m^{-2}·lx^{-1}
Rt: 381 1999 Oct 22 14:56:51 Status: 0

Rl: 136 mcd·m^{-2}·lx^{-1}
Rt: 382 1999 Oct 22 14:57:09 Status: 0

Rl: 197 mcd·m^{-2}·lx^{-1}
Rt: 383 1999 Oct 22 15:01:39 Status: 0

Rl: 208 mcd·m^{-2}·lx^{-1}
Rt: 384 1999 Oct 22 15:02:04 Status: 0

Rl: 189 mcd·m^{-2}·lx^{-1}
Rt: 385 1999 Oct 22 15:02:17 Status: 0

Rl: 122 mcd·m^{-2}·lx^{-1}
Rt: 386 1999 Oct 22 15:05:28 Status: 0

Rl: 118 mcd·m^{-2}·lx^{-1}
Rt: 387 1999 Oct 22 15:05:48 Status: 0

Rl: 132 mcd·m^{-2}·lx^{-1}
Rt: 388 1999 Oct 22 15:06:03 Status: 0

Rl: 128 mcd·m^{-2}·lx^{-1}
Rt: 389 1999 Oct 22 15:09:02 Status: 0

Rl: 74 mcd·m^{-2}·lx^{-1}
Rt: 390 1999 Oct 22 15:09:16 Status: 0

Rl: 77 mcd·m^{-2}·lx^{-1}
Rt: 391 1999 Oct 22 15:09:38 Status: 0

Rl: 214 mcd·m^{-2}·lx^{-1}
Rt: 392 1999 Oct 22 15:13:39 Status: 2

Rl: 184 mcd·m^{-2}·lx^{-1}
Rt: 393 1999 Oct 22 15:14:09 Status: 2

Rl: 164 mcd·m^{-2}·lx^{-1}
Rt: 394 1999 Oct 22 15:14:25 Status: 0

Rl: 164 mcd·m^{-2}·lx^{-1}
Rt: 394 1999 Oct 22 15:14:25 Status: 0

Rl: 164 mcd·m^{-2}·lx^{-1}
Rt: 394 1999 Oct 22 15:14:25 Status: 0

STIMSONITE

STIMSONITE CORPORATION
CERTIFIED TEST REPORT

Re: Certification, Leadfree White Alkyd Thermoplastic

Formulation Code:	W5G-5GX-FF
Manufacturing Order Number:	CO 38352
Purchase Order Number:	19486
Customer name:	BEST STRIPING
Project / Job:	N/A
Quantity Packed:	6 000 LBS
Batch Numbers:	905133-015,016

Item		Required	Found
Composition (Based on Manufacturing Formula)			
Binder		18% Min	18.3
TiO2		10% Min.	10.5
Glass Spheres		40% Min.	41.3
Calcium Carbonate		32% Max	29.9
Physical Characteristics (Actual test data - typical formula)			
Reflectance Rd.		75% Min	84.7
Color		Pure White	Pass
Softening Point		195° F Min	214.7
Low Temp. Stress Resist.		No Cracks	Pass
Specific Gravity		1.9 - 2.3	2.03
Set Time		2 min. @ 50°F	Pass
Indent Resist. (A2)		40-75 @ 110°F	71
Impact Resist.		1.0 N. m Min	Pass
Flash Point (COC)		472° F Min.	490
Retroreflectivity (Mirolux 12)		300 mcd/m$^{2/lux}$ Min	350
Glass Beads (From manufacturer's certification - typical results)			
Refractive Index		1.50 Min	1.51
Percent Spheres		70 Min.	70.8
Percent Passing Sieve:	20	100 Min	100
	30	75-95	90.9
	50	15-35	15.9
	100	0-5	0.3

LEAD CERTIFICATION: **I certify to the best of my knowledge that the material described above contains less than 0.15 ppm lead when tested according to TCLP 40 CFR 261 Method 1311.**

CERTIFICATION: **I certify to the best of my knowledge that the material described above meets all of the requirements of Florida's specification Section 711 and 971.**

Sworn to and subscribed before me this 18th day of May, 1999.

NOTARY PUBLIC

Notary Public
Notary Public, Cobb County, Georgia
My Commission Expires April 26, 2002

Signature

David Fitzgerald
Representative

Q.C. Supervisor
Title

1635 PLYMOUTH ROAD ATLANTA, GEORGIA 30318-2662 404-351-9780 FAX 404-350-9673

STIMSONITE

STIMSONITE CORPORATION
CERTIFIED TEST REPORT

Re: Certification, Leadfree White Alkyd Thermoplastic

Formulation Code:	W5G-5GX-FF
Manufacturing Order Number:	CO 38352
Purchase Order Number	19486
Customer name:	BEST STRIPING
Project / Job:	N/A
Quantity Packed:	6 000 LBS
Batch Numbers:	905133-015,016

Item		Required	Found
Composition (Based on Manufacturing Formula)			
Binder		18% Min	18.3
TiO2		10% Min.	10.5
Glass Spheres		40% Min.	41.3
Calcium Carbonate		32% Max	29.9
Physical Characteristics (Actual test data - typical formula)			
Reflectance Rd.		75% Min	84.7
Color		Pure White	Pass
Softening Point		195° F Min	214.7
Low Temp Stress Resist.		No Cracks	Pass
Specific Gravity		1.9 - 2.3	2.03
Set Time		2 min. @ 50°F	Pass
Indent Resist. (A2)		40-75 @ 110°F	71
Impact Resist.		1.0 N. m Min	Pass
Flash Point (COC)		472° F Min.	490
Retroreflectivity (Mirolux 12)		300 mcd/m^2/lux Min.	350
Glass Beads (From manufacturer's certification - typical results)			
Refractive Index		1.50 Min	1.51
Percent Spheres		70 Min.	70.8
Percent Passing Sieve:	20	100 Min.	100
	30	75-95	90.9
	50	15-35	15.9
	100	0-5	0.3

LEAD CERTIFICATION: **I certify to the best of my knowledge that the material described above contains less than 0.15 ppm lead when tested according to TCLP 40 CFR 261 Method 1311.**

CERTIFICATION: **I certify to the best of my knowledge that the material described above meets all of the requirements of Florida's specification, Section 711 and 971.**

Sworn to and subscribed before me this 19th day of May, 1999.

NOTARY PUBLIC

Notary Public

Notary Public, Cobb County, Georgia
My Commission Expires April 24, 2002

Signature

David Fitzgerald
Representative

Q.C. Supervisor
Title

1635 PLYMOUTH ROAD ATLANTA, GEORGIA 30318-2662 404-351-9780 FAX 404-350-9673

STIMSONITE

STIMSONITE CORPORATION
CERTIFIED TEST REPORT

Re: Certification, **Leadfree White** Alkyd Thermoplastic

Formulation Code:	**W5G-5GX-FF**
Manufacturing Order Number:	CO 38352
Purchase Order Number:	19498
Customer name:	BEST STRIPING
Project / Job:	N/A
Quantity Packed:	6 000 LBS
Batch Numbers:	905133-015,016

Item		Required	Found
Composition (Based on Manufacturing Formula)			
Binder		18% Min	18.3
TiO2		10% Min.	10.5
Glass Spheres		40% Min.	41.3
Calcium Carbonate		32% Max	29.9
Physical Characteristics (Actual test data - typical formula)			
Reflectance Rd		75% Min	84.7
Color		Pure White	Pass
Softening Point		195° F Min	214.7
Low Temp Stress Resist.		No Cracks	Pass
Specific Gravity		1.9 - 2.3	2.33
Set Time		2 min @ 50°F	Pass
Indent Resist (A2)		40-75 @ 110°F	71
Impact Resist.		1.0 N. m Min	Pass
Flash Point (COC)		472° F Min.	490
Retroreflectivity (Mirolux 12)		300 mcd/m^{2}/lux Min	350
Glass Beads (From manufacturer's certification - typical results)			
Refractive Index		1.50 Min	1.51
Percent Spheres		70 Min.	70.8
Percent Passing Sieve	20	100 Min	100
	30	75-95	90.9
	50	15-35	15.9
	100	0-5	0.3

LEAD CERTIFICATION: **I certify to the best of my knowledge that the material described above contains less than 0.15 ppm lead when tested according to TCLP 40 CFR 261 Method 1311.**

CERTIFICATION: **I certify to the best of my knowledge that the material described above meets all of the requirements of Florida's specification, Section 711 and 971.**

Sworn to and subscribed before me this
18th day of May, 1999.

NOTARY PUBLIC

Notary Public
Notary Public, Cobb County, Georgia
My Commission Expires April 24, 2002

Signature

David Fitzgerald
Representative

Q.C. Supervisor
Title

1555 PLYMOUTH ROAD ATLANTA, GEORGIA 30318-2652 404-351-9780 FAX 404-350-9573

STIMSONITE

STIMSONITE CORPORATION
CERTIFIED TEST REPORT

Re: Certification, Leadfree White Alkyd Thermoplastic

Formulation Code:	W5G-5GX-FF
Manufacturing Order Number:	CO 38352
Purchase Order Number:	18498
Customer name:	BEST STRIPING
Project / Job:	N/A
Quantity Packed.	6 000 LBS
Batch Numbers:	905133-015,016

Item		Required	Found
Composition (Based on Manufacturing Formula)			
Binder		18% Min	18.3
TiO2		10% Min	10.5
Glass Spheres		40% Min.	41.3
Calcium Carbonate		32% Max	29.9
Physical Characteristics (Actual test data - typical formula)			
Reflectance Rd.		75% Min	84.7
Color		Pure White	Pass
Softening Point		195° F Min	214.7
Low Temp Stress Resist.		No Cracks	Pass
Specific Gravity		1.9 - 2.3	2.03
Set Time		2 min. @ 50°F	Pass
Indent Resist. (A2)		40-75 @ 110°F	71
Impact Resist.		1.0 N. m Min	Pass
Flash Point (COC)		472° F Min.	490
Retroreflectivity (Mirolux 12)		300 mcd/m^{2}/lux Min	350
Glass Beads (From manufacturer's certification - typical results)			
Refractive Index		1.50 Min	1.51
Percent Spheres		70 Min.	70.8
Percent Passing Sieve:	20	100 Min	100
	30	75-95	90.9
	50	15-35	15.9
	100	0-5	0.3

LEAD CERTIFICATION: **I certify to the best of my knowledge that the material described above contains less than 0.15 ppm lead when tested according to TCLP 40 CFR 261 Method 1311.**

CERTIFICATION: **I certify to the best of my knowledge that the material described above meets all of the requirements of Florida's specification, Section 711 and 971.**

Sworn to and subscribed before me this 18th day of May, 1999.

NOTARY PUBLIC

Notary Public
Notary Public, Cobb County, Georgia
My Commission Expires April 24, 2002

Signature

David Fitzgerald
Representative

Q.C. Supervisor
Title

1566 PLYMOUTH ROAD ATLANTA, GEORGIA 30318-2662 404-351-9750 FAX 404-350-9673

STIMSONITE

STIMSONITE CORPORATION
CERTIFIED TEST REPORT

Re: Certification, Leadfree White Alkyd Thermoplastic

Formulation Code:	W5G-5GX-FF
Manufacturing Order Number:	CO 38352
Purchase Order Number:	19498
Customer name:	BEST STRIPING
Project / Job:	N/A
Quantity Packed:	6 000 LBS

Batch Numbers: 905133-015,016

Item		Required	Found
Composition (Based on Manufacturing Formula)			
Binder		18% Min	18.3
TiO2		10% Min	10.5
Glass Spheres		40% Min.	41.3
Calcium Carbonate		32% Max	29.9
Physical Characteristics (Actual test data - typical formula)			
Reflectance Rd.		75% Min	84.7
Color		Pure White	Pass
Softening Point		195° F Min	214.7
Low Temp. Stress Resist.		No Cracks	Pass
Specific Gravity		1.9 - 2.3	2.33
Set Time		2 min. @ 50°F	Pass
Indent Resist. (A2)		40-75 @ 110°F	71
Impact Resist.		1.0 N. m Min	Pass
Flash Point (COC)		472° F Min.	490
Retroreflectivity (Mirolux 12)		300 mcd/m^{2}/lux Min	350
Glass Beads (From manufacturer's certification - typical results)			
Refractive Index		1.50 Min	1.51
Percent Spheres		70 Min.	70.8
Percent Passing Sieve:	20	100 Min	100
	30	75-95	90.9
	50	15-35	15.9
	100	0-5	0.3

LEAD CERTIFICATION: **I certify to the best of my knowledge that the material described above contains less than 0.15 ppm lead when tested according to TCLP 40 CFR 261 Method 1311.**

CERTIFICATION: **I certify to the best of my knowledge that the material described above meets all of the requirements of Florida's specification, Section 711 and 971.**

Sworn to and subscribed before me this 18th day of May, 1999.

NOTARY PUBLIC

Notary Public
Notary Public, Cobb County, Georgia
My Commission Expires April 24, 2002

Signature

David Filzgerald
Representative

Q.C. Supervisor
Title

1635 PELHAM ROAD ATLANTA, GEORGIA 30316-2662 404-351-9780 FAX 404-350-9573

Flex-O-Lite, Inc.
1601 Northwest 19th Street
Paris, Texas 75460
903-785-1633 (34)
FAX: 903-785-8220

Ron Thomas
Plant Manager

I certify that the shipment to Best Striping Inc was inspected and found to comply with all requirements of the Florida Type I Dual Coated specification.

Quantity	12,000#
Customer No.	19702
Lot No.	9179952
Date	9-20-99
Ship VIA	Skidmore

Sieve	% Retained	%Round
20	0	
30	9.8	71.0
50	73.5	80.5
100	99.0	83.0

Index of Refraction	+1.50
% Round	78.1
Moisture Test	Passed
Specific Gravity	2.50
Starbrite	Passed

Signature Steve M Kennedy
Title Quality Control Technician
Date 9-20-99

Flex-O-Lite, Inc.

Flex-O-Lite, Inc.
1601 Northwest 19th Street
Paris, Texas 75460
903-785-1633 (34)
FAX: 903-785-8220

Ron Thomas
Plant Manager

I certify that the shipment to Best Striping Inc was inspected and found to comply with all requirements of the Florida Type I Dual Coated specification.

Quantity	12,000#
Customer No.	19702
Lot No.	9179952
Date	9-20-99
Ship VIA	Skidmore

Sieve	% Retained	%Round
20	0	
30	9.8	71.0
50	73.5	80.5
100	99.0	83.0

Index of Refraction	+1.50
% Round	78.1
Moisture Test	Passed
Specific Gravity	2.50
Starbrite	Passed

Signature Steve M Kennedy
Title Quality Control Technician
Date 9-20-99

Flex-O-Lite, Inc.

Flex-O-Lite, Inc.
1601 Northwest 19th Street
Paris, Texas 75460
903-785-1633 (34)
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20	0	
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50	73.5	80.5
100	99.0	83.0

Index of Refraction	+1.50
% Round	78.1
Moisture Test	Passed
Specific Gravity	2.50
Starbrite	Passed

Signature Steve M. Kennedy
Title Quality Control Technician
Date 9-20-99

Flex-O-Lite, Inc.

Flex-O-Lite, Inc.
1601 Northwest 19th Street
Paris, Texas 75460
903-785-1633 (34)
FAX: 903-785-8220

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Date	9-20-99
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Sieve	% Retained	%Round
20	0	
30	9.8	71.0
50	73.5	80.5
100	99.0	83.0

Index of Refraction	+1.50
% Round	78.1
Moisture Test	Passed
Specific Gravity	2.50
Starbrite	Passed

Signature Alex T Kennedy
Title Quality Control Technician
Date 9-20-99

Flex-O-Lite, Inc.

Flex-O-Lite, Inc.
1601 Northwest 19th Street
Paris, Texas 75460
903-785-1633 (34)
FAX: 903-785-8220

Ron Thomas
Plant Manager

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Customer No.	19702
Lot No.	9179952
Date	9-20-99
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Sieve	% Retained	%Round
20	0	
30	9.8	71.0
50	73.5	80.5
100	99.0	83.0

Index of Refraction	+1.50
% Round	78.1
Moisture Test	Passed
Specific Gravity	2.50
Starbrite	Passed

Signature Steve M Kennedy
Title Quality Control Technician
Date 9-20-99

Flex-O-Lite, Inc.