EVALUATION OF THERMOPLASTIC MATERIALS

FINAL REPORT

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ABSTRACT

In order to find a striping material which would last longer and have greater reflectance than the presently used traffic paint, research was performed on three relatively new thermoplastic marking compounds. The manufacturers of these products claim that the thermoplastic materials have longer life expectancies and higher reflectance values than the presently used traffic paint. Actual field installations were made in order to determine the validity of this statement.

Installations were made on four types of roadway surfaces: old concrete, new concrete, old asphalt and new asphalt. Reflectance readings and field inspections were made periodically of both the thermoplastic material and the traffic paint.

The results obtained showed that the reflectance of one-year-old white thermoplastic material was generally equal to the initial reflectance of the white traffic paint. The reflectance readings of the yellow thermoplastic material and the yellow traffic paint were relatively close for the first 6 months.

Periodic inspections showed that the thermoplastic compound had much more abrasion resistance than the traffic paint. After 30 months of wear, the thermoplastic marking material had a negligible amount of loss due to abrasion. However, the painted stripes were completely worn after only 1 year.

Specifications for quality control have been developed based upon laboratory analysis of the thermoplastic material.

IMPLEMENTATION

Results obtained in the laboratory and the field were used in writing a general set of specifications for thermoplastic marking compounds.

These specifications are to be used as minimum requirements in order to obtain a high quality thermoplastic marking compound which can be applied to either bituminous or Portland Cement concrete pavement. The most significant requirements of the compound are reflectance, durability, adhesion strength and impact resistance.

Physical requirements of glass beads, which are used with the thermoplastic compound for added reflectance, are also included. In particular, the size, refractive index and maximum percent of inferior beads are specified.

In addition to the previously mentioned requirements, application equipment and techniques are also described in the specifications.

These specifications were implemented in the quality control of thermoplastic material used for two striping operations on LDH Project No. 60-01-23 and LDH Project No. 741-00-20, 741-00-21.

EVALUATION OF THERMOPLASTIC MATERIALS

INTRODUCTION

It is becoming increasingly dangerous for striping crews to operate on heavily traveled highways. Higher traffic densities not only wear the painted lines faster but also make the needed reapplications much more hazardous to the motoring public.

A painted traffic line is inexpensive to install--approximately $0.025 per foot for a 4-inch width. The life expectancy of such a painted line is from 6 to 12 months depending on traffic volume. This line begins to lose its effectiveness within 3 months after the installation date.

This research project was to determine if the new types of thermoplastic compounds, using various thicknesses and methods of application, give a substantial increase in effective life of a stripe. However, a cost analysis was necessary to justify the use of these compounds.

SCOPE

The scope was to evaluate the performance of three types of thermoplastic striping compounds placed on both old and new concrete and asphaltic surfaces. The thermoplastic materials were subjected to field and laboratory tests. The objective of the field evaluation was to determine which material was superior. The objective of the laboratory analysis was to develop specifications which would be characteristic of the superior thermoplastic material.

A cost analysis, based upon an estimated life expectancy of the thermoplastic material, has been completed.

Phase I (Road Installation)

The present LDH traffic marking pattern was followed for each thermoplastic marking material. This striping pattern is a 15-foot line, four inches wide, for every 40 feet of roadway. Thus, in one mile of roadway, there are 1980 linear feet of marked surface. Each respective thermoplastic pavement marking material was applied for 1/2 mile at 60 mils, and 1/2 mils at 125 mils thickness on both old and new concrete and asphaltic surfaces.

The three manufacturers represented in the field installation were: (1) Pave-Mark Contractors, (2) Perma-Line Corporation of America and (3) Cataphote Corporation.

The material was applied to the pavement by both spray and extrusion methods. The application of thermoplastic marking material at 60 mils thickness was best accomplished by the spray method; whereas, the application of thermoplastic marking material at 125 mils thickness was best accomplished by the extrusion method. In the extrusion method, one side of the extrusion shaping die was the pavement and the other sides were formed by suitable equipment for heating and controlling the flow of the material. Glass spheres were then applied, almost instantaneously, to the surface of the completed stripe by an automatic bead dispenser at a controlled rate of flow.

On concrete pavement surfaces, as recommended by the manufacturers, a binder-sealer material was applied to the road surface prior to the actual thermoplastic installation. All dust, debris and other foreign matter were removed from the road surface immediately prior to the installation of the material. In addition to the normal field installations, one of the companies, Cataphote Corporation, at the request of the Department installed their product at LA-37 and I-12 without the application of the recommended binder-sealer material.

To insure optimum adhesion, the thermoplastic material was installed in a melted state at a temperature of 375^{o} F to 425^{o} F.

The four locations selected for installation were: (1) La-37 (Greenwell Springs Road), (2) U. S. 61 (Airline Highway), (3) La-30 and (4) I-12.

Reflectance readings of these road installations were taken at the time of installation and at the end of 1 month, 2 months, 3 months, 6 months, 12 months, 20 months and 30 months after installation. The instrumentation used to measure the reflectance consisted of a light-sensitive probe mounted on a tripod and a digital read-out apparatus connected to the probe, as can be seen in Figure 1. The tripod was erected in the back of a pickup truck just behind the driver. The probe was focused on the traffic stripe 25 feet from the front end of the truck .

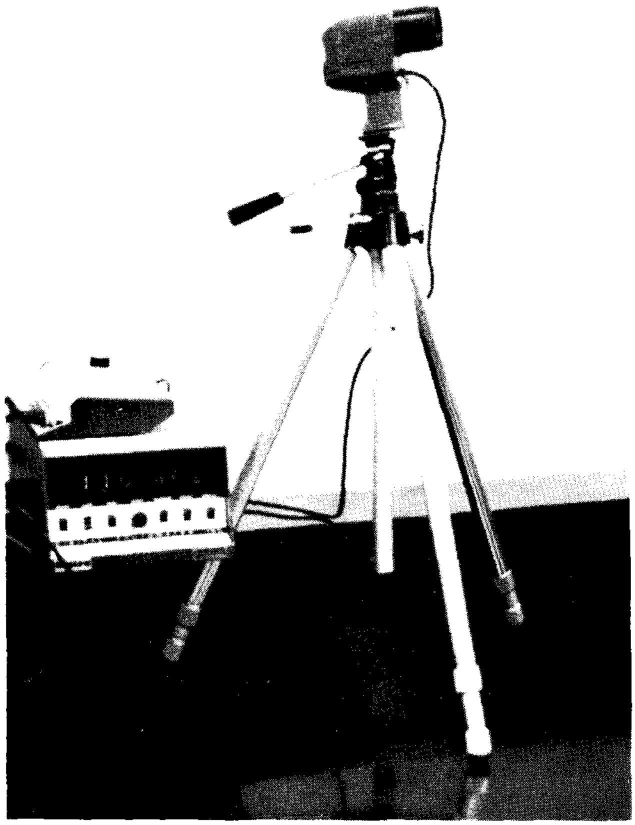


Figure 1. Instrumentation Used to Measure Reflectance Readings

Phase II (Laboratory Analysis)

Several laboratory tests were conducted on the thermoplastic material, thus yielding results pertaining to both the physical and chemical properties.

The melting poing and the adhesion strength were calculated for the thermoplastic material. (Refer to Test Procedure 1 in the Appendix and Figure 2 below.)

The amount (Test Procedure 2 in the Appendix) and size (ASTM Designation: D 1214) of the beads present in the thermoplastic compound were determined. The beads were also analyzed by the immersion method to determine the refractive index, and the percent of unsatisfactory beads present was determined by ASTM Designation: D 1155.

The results of these laboratory tests were used in writing the specifications for the thermoplastic material.

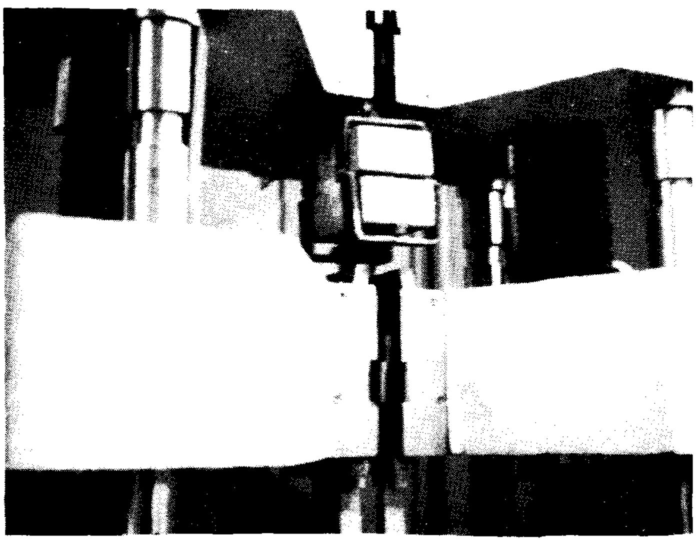


Figure 2. Apparatus Used To Test For Adhesion Strength

RESULTS

Field Results

Reflectivity

When compared to the reflectance readings of the presently used white traffic paint, the reflectance quality of the white thermoplastic compound was generally determined to be superior for the same period of exposure except for one of the nine applications, as shown in tables 1 through 3 and figures 15 through 17 of the Appendix.

The major decrease in reflectivity occurred during the first 18 months of exposure. At the end of $2\frac{1}{2}$ years of exposure, the average reflectivity ranged between 0.06×10^{-3} and 0.13×10^{-3} foot lamberts.

The reflectance readings of the yellow thermoplastic compound and the yellow traffic paint were relatively close after 6 months, as indicated in Table 4 and Figure 18 of the Appendix.

Figure 3 below shows an accumulation of road film on the white thermoplastic marking. This accumulation caused a decrease in reflectance. Figure 4 shows thermoplastic material which was not exposed to traffic wear.

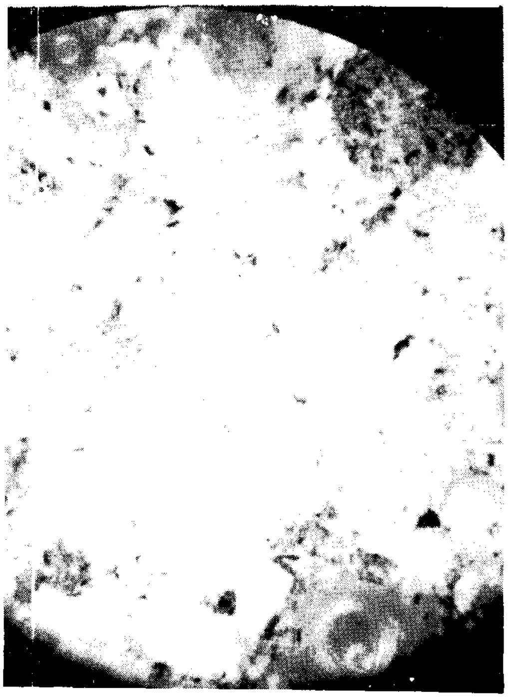


Figure 3. Material Exposed to Traffic Wear for 30 Months (52x)

Figure 4. Material Not Exposed to Traffic Wear (52x)

Wearability

The wearability of the thermoplastic compound was found to be superior to that of the traffic paint. The painted markings were found to be badly worn and in need of repainting after 1 year of installation. After $2\frac{1}{2}$ to 3 years, the amount of wear of the thermoplastic material was found to be negligible. However, microscopic flaking was present.

Cracks extending across the width of the thermoplastic stripe, as seen in Figure 5, were caused by differential expansion of the stripe and the roadway surface.

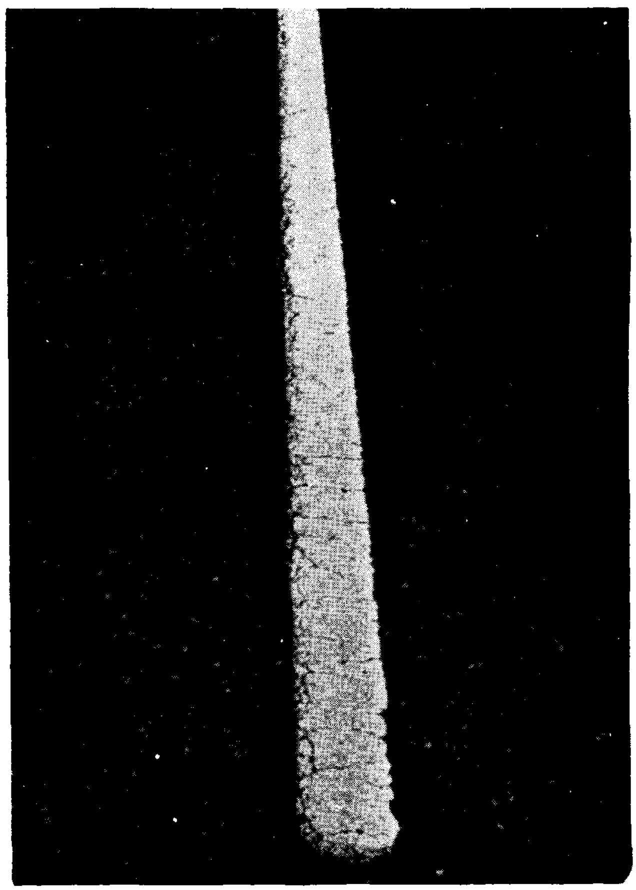


Figure 5. Transverse Cracking of Thermoplastic Material

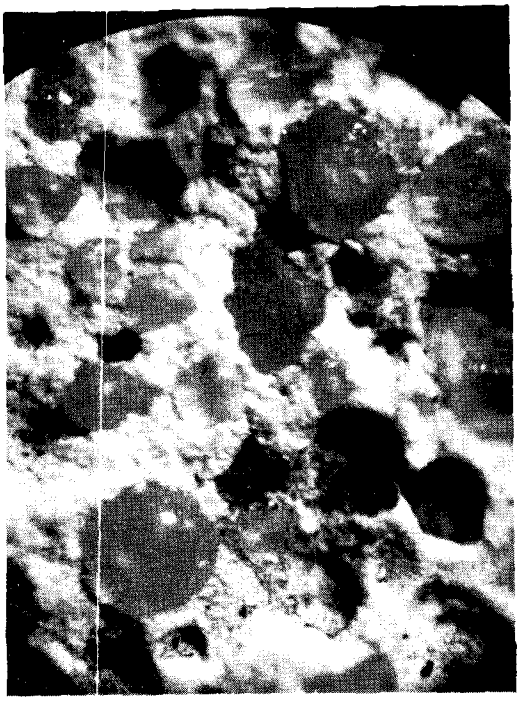


Figure 6. Abrasion of Glass Spheres in Thermoplastic Materials (52x)

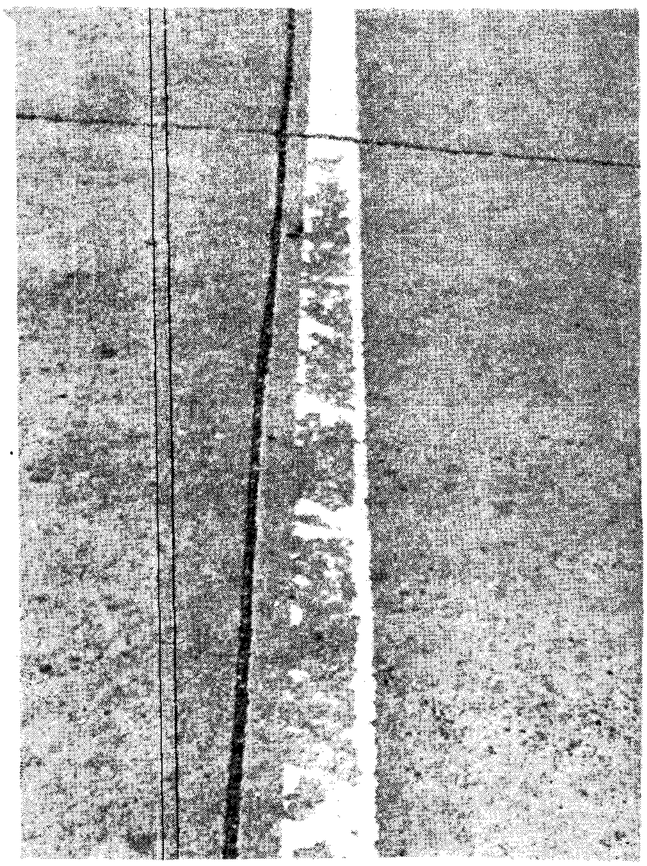
Glass beads, originally perfect spheres, became worn and broken as can be seen in Figure 6. These defective beads resulted in a lower reflectance of the traffic stripe.

Many of the glass beads at the surface were removed by traffic wear, leaving small depressions in the thermoplastic material. These depressions, as can be seen in Figure 7, were available areas for accumulation of road film causing a decrease in reflectivity.

Figure 7. Depressions Left By Removal of Glass Spheres (52x)

Adhesion

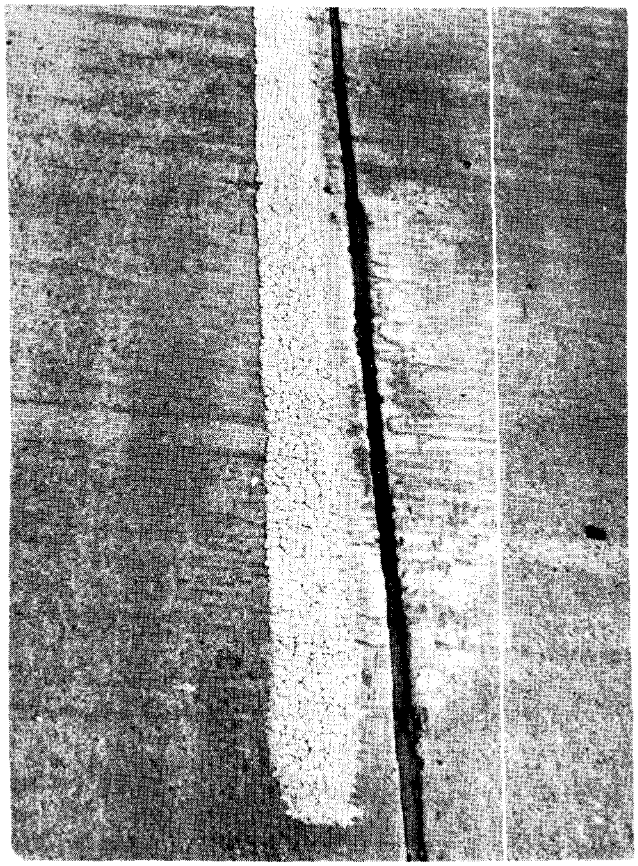
Adhesion of the thermoplastic material to the existing painted stripes on the road surface was tested by applying 7½ feet of the thermoplastic stripe over the painted stripe and 7½ feet over the roadway. The appropriate primer was used prior to the application over concrete. After 2½ years of wear, the material adhered satisfactorily to the roadway. However, adhesion of the material to the paint was poor, as shown in figures 8 and 9.



Figures 8 and 9. Poor Adhesion of Thermoplastic Material Applied over Original Painted Stripe

Application over an improperly cleaned surface produced the results shown in Figure 10 when the thermoplastic material was applied on a section of road which had been tracked with mud by trucks in one area.

Figure 10. Poor Adhesion of Thermoplastic Material to Improperly Cleaned Surface

Figures 11 and 12. Thermoplastic Material Applied to Improperly Primed Concrete

A major difference in the adhesion of the thermoplastic material was noticed when the material was placed on the concrete roadway without first using the binder-sealer material as a primer. All of the stripes applied in this manner had failed within 6 months, due to poor binding, as can be seen in figures 11, 12 and 13. However, the primer was found to be unnecessary when applying the thermoplastic compound to asphaltic roadway. There was no significant difference between the adhesion of the thermoplastic compound on new and old asphalt and new and old concrete, as long as the primer was used prior to application on concrete.

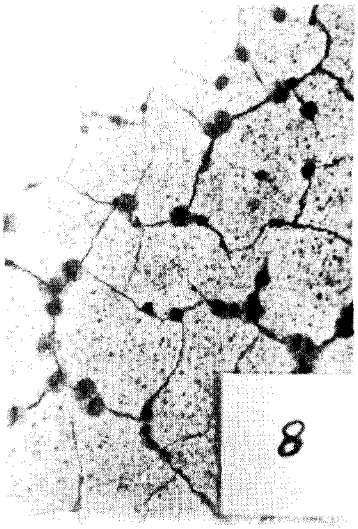


Figure 13. Cracks in Thermoplastic Material Resulting From Application to Concrete Without Recommended Primer

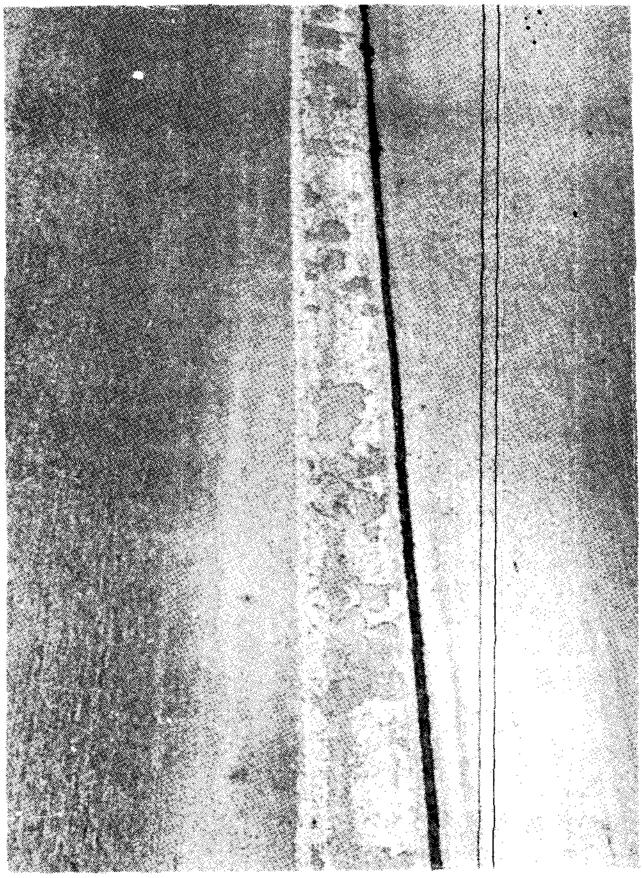


Figure 14. Thermoplastic Material Applied Below Required Temperature

A problem in adhesion, shown in Figure 14, was noted when four thermoplastic stripes were installed before the material had reached the recommended application temperature of 375° F to 425° F.

Application

Two methods of applying the thermoplastic material were employed: (1) the spray method and (2) the extrusion method. The spray method was satisfactory for the 1/16-inch thick stripes. However, the spray did not produce the thickness required for a 1/8-inch thick stripe. The extrusion method produced a 1/8-inch thick stripe having the required thickness and much sharper edges.

Curing Time

The curing time of the thermoplastic material varied from 60 to 120 seconds, depending on ambient air temperature.

Laboratory Results

The laboratory tests showed that all the thermoplastic materials have the same melting point of 290° F.

The adhesion strength varied for the three materials (Table 5 of the Appendix). Perma-Line thermoplastic had the highest value of 180.2 psi. The material made by Pave-Mark had a value of 161.5 psi. The material produced by Cataphote produced the lowest value of 107.6 psi for adhesion strength.

The drop-on beads of the Pave-Mark thermoplastic material were the largest in size (Table 6 of the Appendix). However, the drop-on beads of the Perma-Line and Cataphote thermoplastic were approximately equal to one another in size, according to the sieve analysis.

The refractive index of the drop-on beads of all the thermoplastic materials was found to be between 1.55 and 1.56. The percent of poor quality drop-on beads ranged from 15% to 25% (Table 6 of the Appendix).

The beads contained in the thermoplastic materials was calculated to be approximately 50% by weight (Table 7 of the Appendix).

DISCUSSION OF RESULTS

The reflectance readings of the yellow thermoplastic compound and the yellow traffic paint were relatively close for the period evaluated. The evaluation of the yellow traffic paint and thermoplastic compound was concluded after the sixth month reflectance readings, as this test section was overlaid with asphalt.

As a whole, the reflectance readings of the white thermoplastic materials were initially two times higher than those of the white traffic paint presently used for striping, as indicated in figures 15, 16 and 17 of the Appendix. After a period of 1 year, the reflectance of the white thermoplastic markings had dropped to one-half of the original reflectance.

The reflectance loss of the thermoplastic markings was primarily caused by a buildup of road film. The highly abrasion-resistant thermoplastic marking did not wear as fast as the presently used painted marking and was, therefore, more susceptible to accumulating a road film. Observation of the reflectivity data in figures 15, 16 and 17 of the Appendix showed that the road film buildup had a maximum accumulation after 1½ years and therefore caused a negligible amount of further decrease in reflectivity.

The other factor contributing to reflectance loss was the abrasion of the glass beads.

When observed through a microscope, glass beads present in a sample of the thermoplastic material taken from the field, after an exposure time of 2½ to 3 years, were found to be damaged. This factor also contributes, at least partially, to the decrease in reflectivity.

It was previously stated that at the end of 2½ years of exposure, the reflectance readings ranged from 0.06×10^{-3} to 0.13×10^{-3} foot lamberts, as shown in tables 1 through 3 and figures 15 through 17 of the Appendix.

On both U.S. 61 (new asphalt) and I-12 (new concrete), the reflectivity of the three thermoplastic compounds did not differ as much as on LA-37 (old concrete). After 30 months, the range of the average values found on U.S. 61 were between 0.07×10^{-3} and 0.08×10^{-3} foot lamberts as compared to 0.11×10^{-3} and 0.12×10^{-3} foot lamberts found on I-12.

The greatest range of reflectivity found on LA-37 was 0.06×10^{-3} foot lamberts for Pave-Mark as compared to 0.13×10^{-3} foot lamberts for Cataphote after 30 months of exposure. The variation of the reflectivity may have been due to overhead lighting present along the section of road used in this field evaluation.

Adhesion of the thermoplastic material was found to be satisfactory when applied to a clean asphalt surface or a primed, clean concrete surface at the proper temperature.

There was no effect upon the reflectance readings due to the thickness variation of the thermoplastic material. Also, the effect of thickness variation did not appear to have a bearing upon the rate of wear of the material. This constant wear rate would indicate that the initially thicker thermoplastic stripe would have a longer life expectancy. A projected life expectancy of the marking compound was estimated to be at least 5 years compared to 6 to 12 months for the presently used traffic paint.

The cost of installing a 4-inch wide stripe using the thermoplastic material was determined to be $0.35 per linear foot at a thickness of 125 mils. Installation of a 4-inch wide stripe using traffic paint was determined to cost approximately $0.025 per linear foot.

Based upon a life expectancy of 10 years for the thermoplastic material and 9 months for the traffic paint, the total cost to install a 4-inch wide stripe using the thermoplastic material and traffic paint over a period of 10 years was calculated to be $0.35 per foot and $0.33 per foot, respectively. However, it should be pointed out that a life expectancy of 10 years cannot yet be verified due to insufficient field exposure. Furthermore, a full life expectancy can only be realized if resurfacing of the roadway does not occur during this time.

CONCLUSIONS

Based upon the results obtained, it has been concluded that:

1. All of the thermoplastic compounds were of good quality, based upon the current test results.

2. The thermoplastic material was found to have a greater resistance to abrasion than traffic paint.

3. The initial reflectance of the white thermoplastic material was twice as high than that of the white traffic paint.

4. The thermoplastic material became dirty after installation. This accounted for the drop in reflectance readings, even though the stripes were not extensively worn. However, further examination of these stripes showed that the buildup of road film reached a maximum at 18 months causing reflectivity readings to level out.

5. Damage and loss of glass beads also contributed to the decrease in reflectivity of the thermoplastic material.

6. The thermoplastic material should not be installed without the use of the proper primer and until the material is preheated to the proper temperature.

7. Application of thermoplastic material at 60 mils was best accomplished by the spray method, and the application of thermoplastic material at 125 mils was best accomplished by the extrusion method.

8. Life expectancy of the thermoplastic marking compound has been estimated to be at least 5 years. (Life expectancy of standard paint was found to be from 6 to 12 months.)

RECOMMENDATIONS

Justification of the use of the thermoplastic marking compound in place of the presently used traffic paint depends primarily upon--life expectancy versus cost. This comparison justifies the use of thermoplastic marking compound as a substitute for the currently used striping paint only if a 10-year life expectancy of the material can be realized and if the roadway is not resurfaced prior to the end of the 10-year period.

Other important factors which should be considered are the safety of the striping crew and the public inconvenience during each striping operation. Use of the traffic paint, as compared to the thermoplastic material, requires more frequent striping.

Specifications have been developed for the thermoplastic marking compound. Due to the reflectance readings and the wearability, all of the thermoplastic materials appear to be of equally good quality. The physical and chemical properties of these materials are all similar. It is, therefore, reasonable to adopt one set of specifications to satisfy all of the thermoplastic marking material to be used by the Louisiana Department of Highways.

APPENDIX

Test Procedure 1 - Adhesion Test

1. Two cement blocks, 2" x 3-1/2" x 7", are preheated to 200^{o} F (93^{o} C).

2. These two blocks are bonded together on the 3-1/2" x 7" faces with a 1/8" layer of thermoplastic material which has been heated to a temperature of 325^{o} F (163^{o} C).

3. These blocks are then placed into a set of braces to be pulled apart by a tension apparatus.

4. The blocks are then pulled until breakage occurs due to adhesion or cohesion failure (refer to Figure 1).

5. The load, in pounds, required to produce the failure is recorded.

6. The surface area of the thermoplastic bond is measured.

7. The adhesion strength is calculated by the following equation:

$$\text{Adhesion strength (psi)} = \frac{\text{load at failure (lbs.)}}{\text{surface area of bond (in}^2\text{)}}$$

Test Procedure 2 - Determination of Beads in Thermoplastic Marking Compound

1. Weigh 100 grams of thermoplastic compound in a 250-ml beaker.

2. Fill the beaker 3/4 full of chlorothane and let stand for 48 hours.

3. Wash the beads 3-4 times, decanting the liquid after each washing.

4. Put the beaker into the oven for 1 hour.

5. Weigh the beaker and dried beads.

6. The percent of beads in the thermoplastic materials is calculated by the following equation:

$$\%\ \text{beads} = \frac{\text{weight of dried beads}}{\text{weight of original thermoplastic samples}}$$

TABLE 1

AVERAGE REFLECTANCE READINGS (Foot Lamberts X 10^{-3})

LOCATION: I-12

COLOR OF MATERIAL: White

Exposure Time (Months)	Pave-Mark Thermoplastic	Perma-Line Thermoplastic	Cataphote Thermoplastic	Standard LDH Paint
0	---	---	---	.18
1	.20	.23	.38	.15
2	.24	.27	.31	.15
3	.18	.21	.28	---
6	.13	.13	.20	.14
12	.13	.10	.15	Completely Worn
20	.09	.11	.11	
30	.12	.11	.12	

TABLE 2

AVERAGE REFLECTANCE READINGS (Foot Lamberts x 10^{-3})

LOCATION: U. S. 61

COLOR OF MATERIAL: White

Exposure Time (Months)	Pave-Mark Thermoplastic	Perma-Line Thermoplastic	Cataphote Thermoplastic	Standard LDH Paint
0	---	---	---	.15
1	.15	.22	.23	.08
2	.07	.16	.17	.12
3	.09	.21	.10	---
6	.07	.10	.11	.13
12	.06	.07	.08	Completely Worn
20	.05	.06	.08	
30	.07	.07	.08	

TABLE 5

AVERAGE ADHESION STRENGTH OF THERMOPLASTIC MATERIALS (PSI)

Material	Surface Area (sq. in.)	Load (lbs.)	Adhesion Strength (psi)
Perma-Line	10.545	1900	180.2
Pave Mark	13.125	2120	161.5
Cataphote	10.312	1110	107.6

Note: 1. The thermoplastic material was preheated to 325^{o} F.

2. The cement blocks used were preheated to 200^{o} F.

TABLE 6

AVERAGE GRADATION OF GLASS BEADS

USED FOR DROP-ON THERMOPLASTIC MATERIAL

	Pave Mark	Perma-Line	[illegible]
Sieve Analysis			
Passed #10 Retained on #40	75.2%	43.0%	41.[illegible]
Passed #40 Retained on #80	20.0%	49.6%	17.[illegible]
Passed #80 Retained on #200	4.1%	7.4%	[illegible]
Passed #200	0.7%	0.3%	[illegible]
Refractive Index	1.55	1.55	[illegible]
Beads Showing Poor Quality	15 - 20%	20 - 25%	[illegible]

TABLE 7

AVERAGE PERCENT (BY WT.) OF GLASS BEADS

CONTAINED IN THERMOPLASTIC MATERIAL

	Pave Mark	Perma-Line	Cataphote
White	44.0%	45.8%	57.5%
Yellow	49.0%	46.9%	42.3%

FIGURE 15

AVERAGE REFLECTANCE READINGS

LOCATION: I-12

COLOR OF MATERIAL: WHITE

TYPE OF SURFACE: NEW CONCRETE

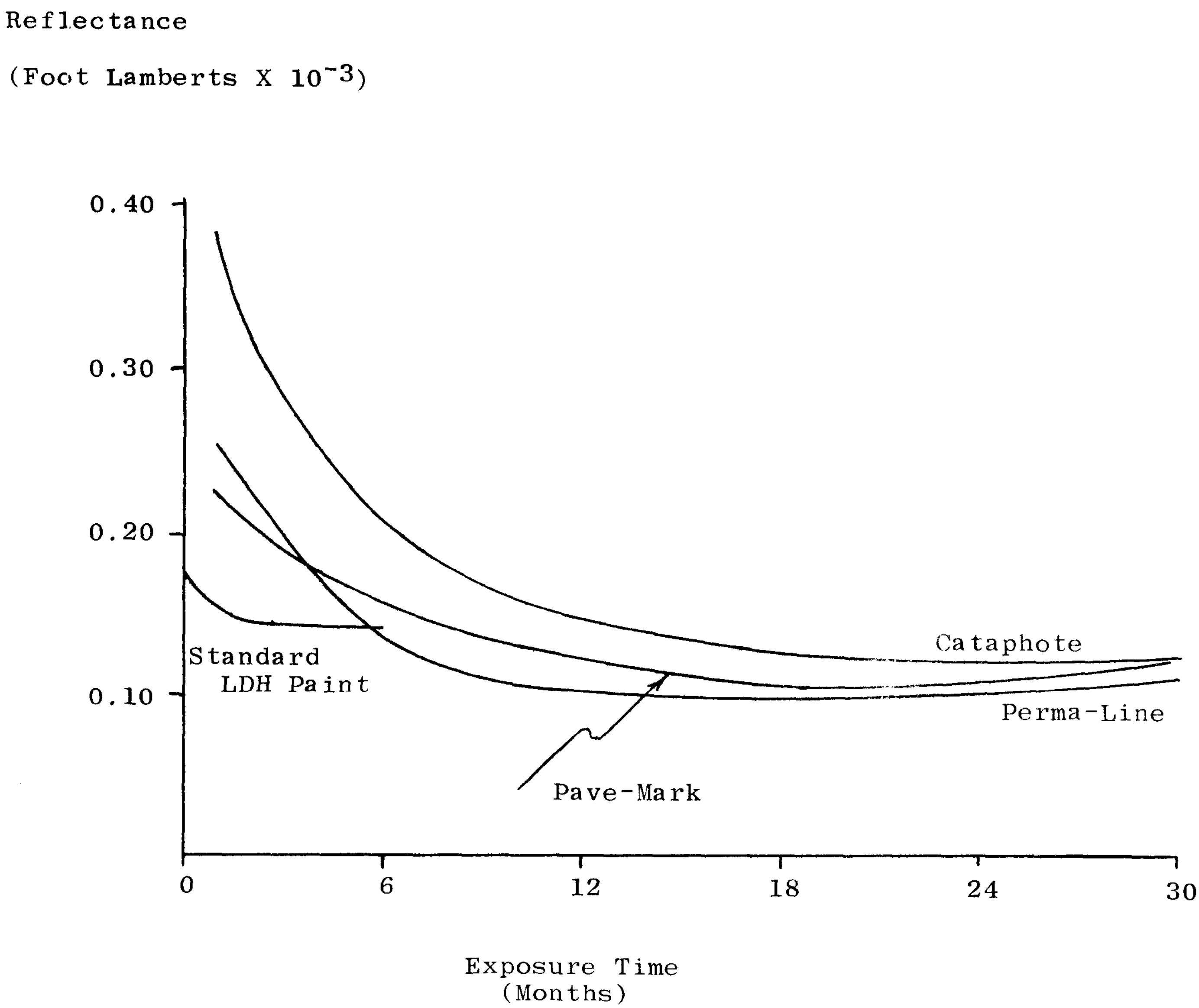


FIGURE 16

AVERAGE REFLECTANCE READINGS

LOCATION: U.S. 61

COLOR OF MATERIAL: WHITE

TYPE OF SURFACE: NEW ASPHALT

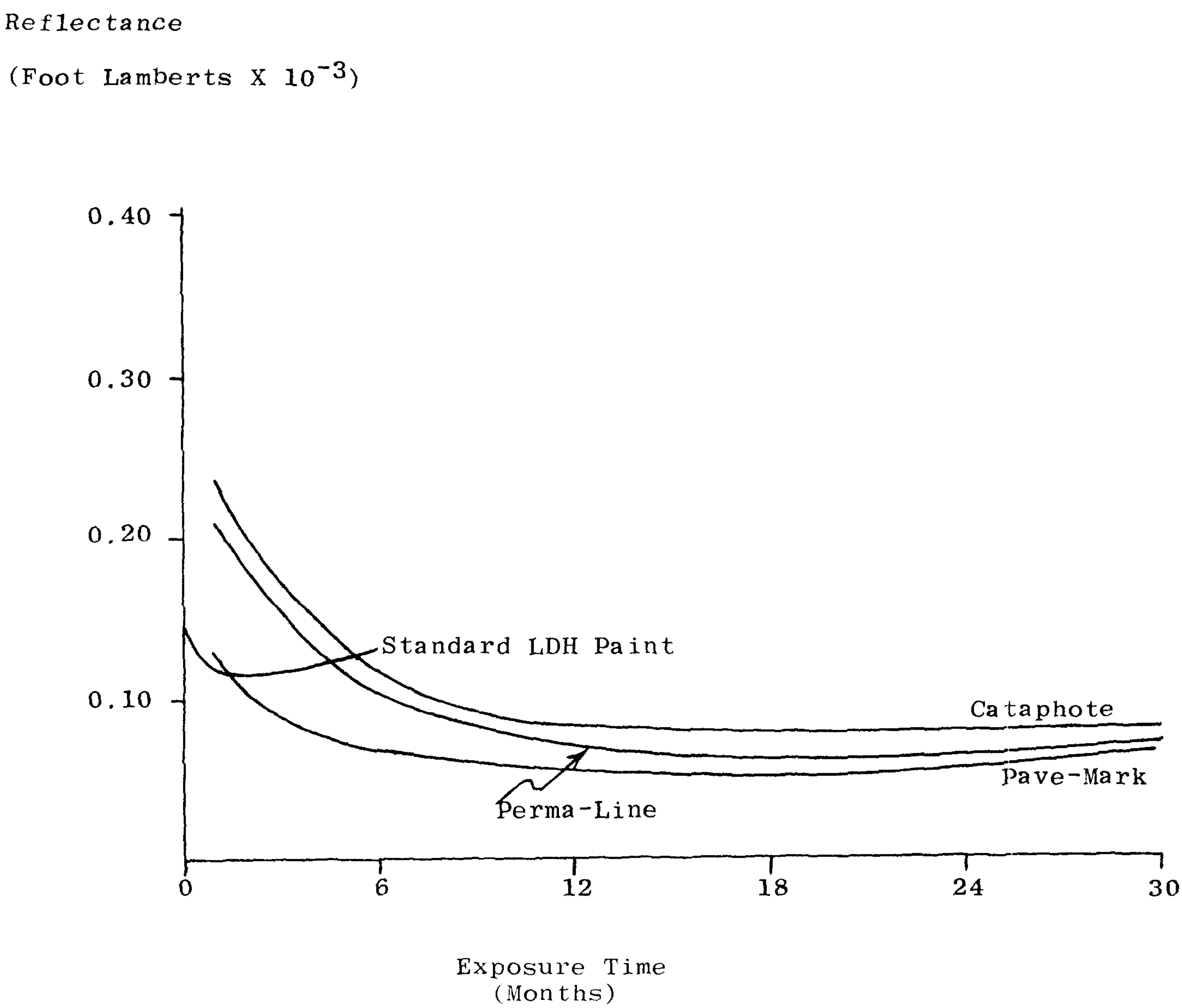


FIGURE 17

AVERAGE REFLECTANCE READINGS

LOCATION: LA-37

COLOR OF MATERIAL: WHITE

TYPE OF SURFACE: OLD CONCRETE

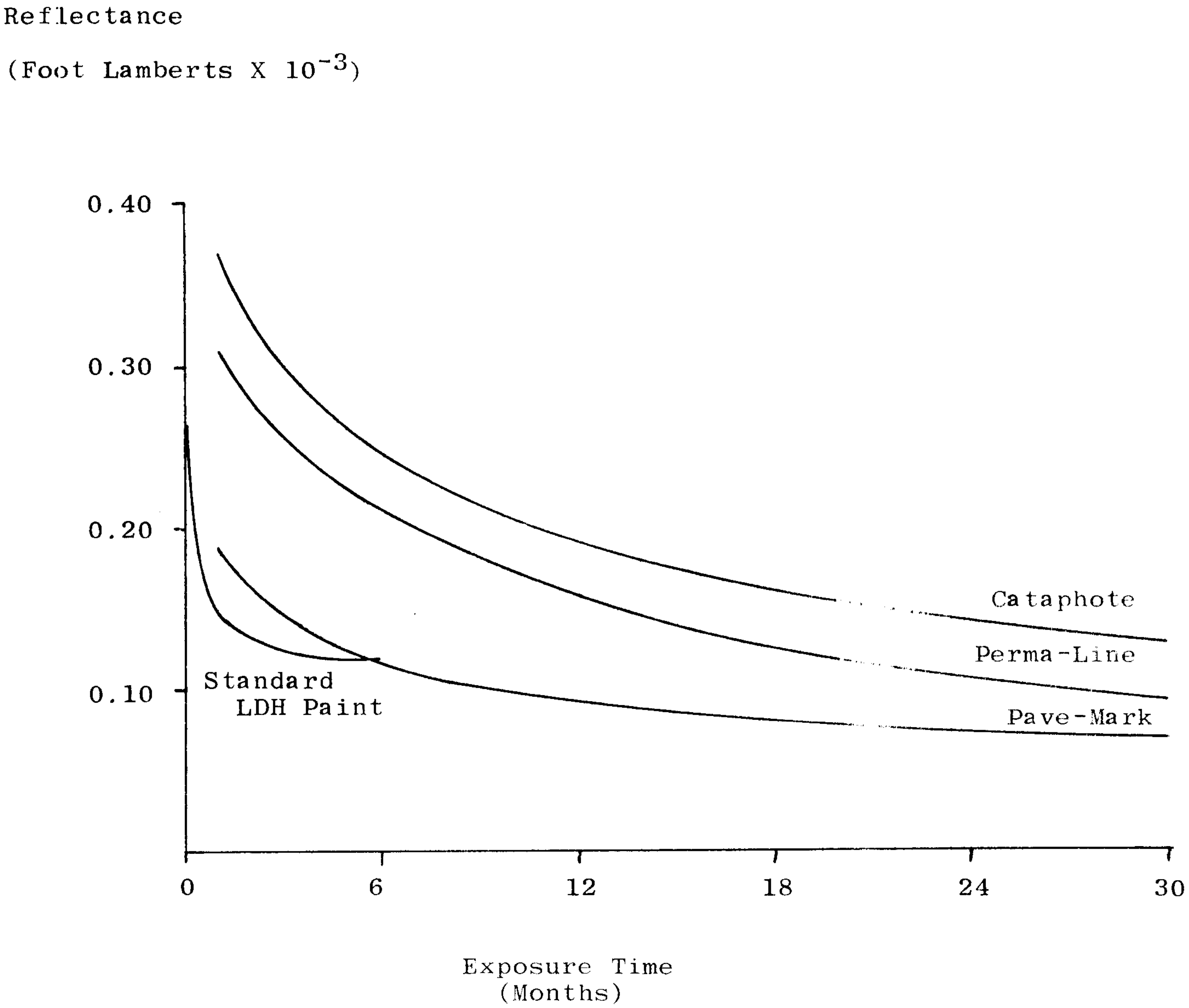


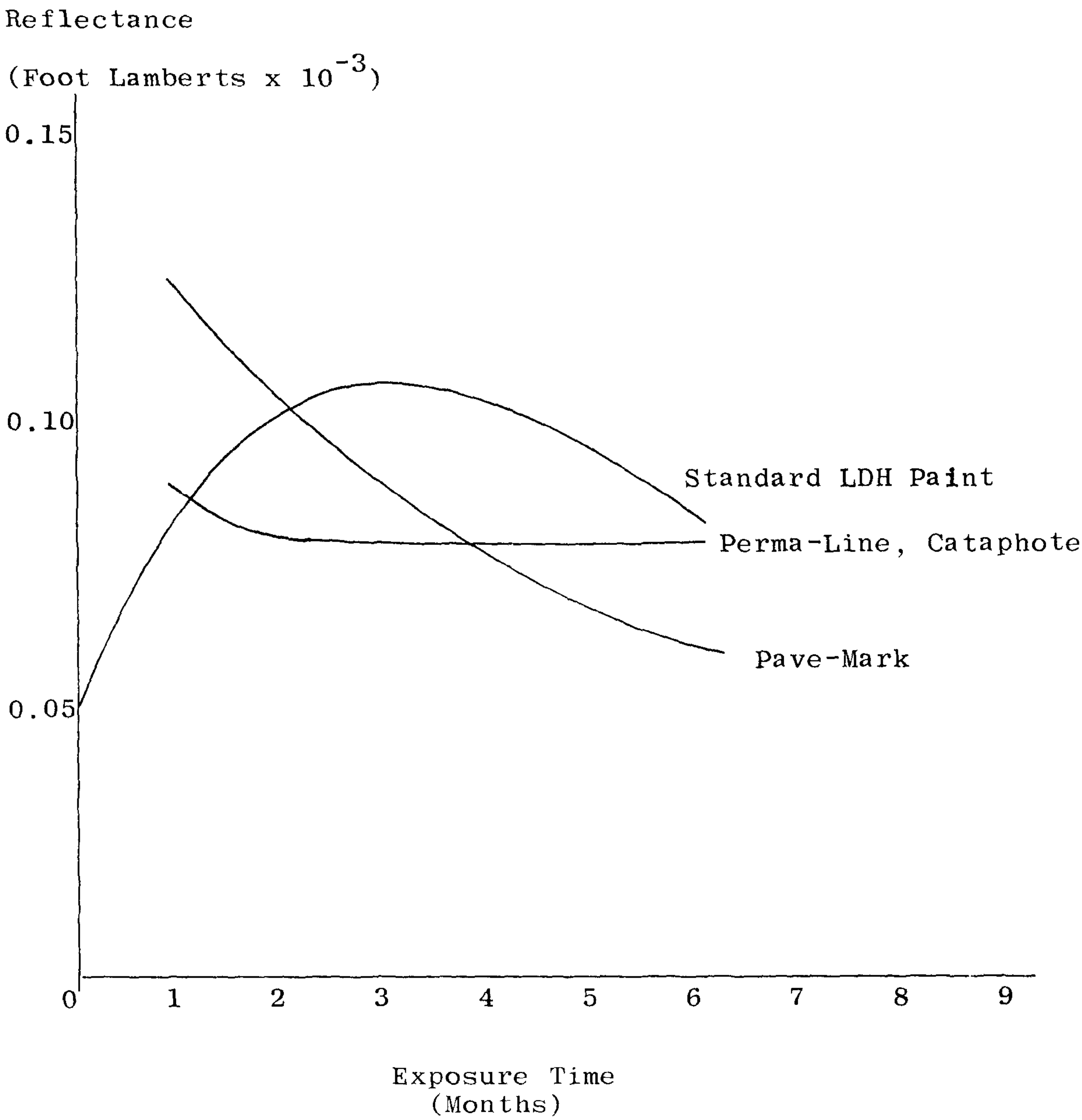
FIGURE 18

AVERAGE REFLECTANCE READINGS

LOCATION: LA-30

COLOR OF MATERIAL: YELLOW

TYPE OF SURFACE: OLD ASPHALT



SPECIFICATIONS FOR THE INSTALLATION OF THERMOPLASTIC PAVEMENT MARKINGS

I. Scope

This specification covers hot extruded, 100% solids, reflective thermoplastic compound for use as pavement markings on bituminous and Portland cement concrete pavement. The material shall be manufactured so as to be applied only by extrusion means onto the pavement in molten form, with internal and surface application of glass spheres. Upon cooling to normal pavement temperature, the material shall produce an adherent reflectorized pavement marking of specified thickness and width and it shall be capable of resisting deformation.

This specification is intended to set minimum requirements on material characteristics of the thermoplastic compound and an application method in order to secure acceptable performance of field service.

II. General Characteristics

Neither the oil content of pavement materials nor the oil droppings of the traffic shall deteriorate the compound. In the molten state, materials 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 molten temperature for a period of four hours, or if subjected to four reheatings to the molten temperature. The temperature versus viscosity characteristics of the plastic material shall remain constant throughout up to four repeatings or from batch to batch. To insure the best possible adhesion, the compound, as specified, shall be installed in a melted state, at a temperature of 375° F to 425° F, and the material shall not scorch or discolor if kept at this temperature for up to four hours.

a) 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 20% nor more than 35% by weight. 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. The fillers shall be a white calcium carbonate or equivalent.

b) Suitability for Application

The thermoplastic material shall be a product especially compounded for traffic markings. The markings shall maintain their original dimension and placement and shall not smear or spread under normal traffic conditions at temperatures below 140° 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. When cooled, the exposed surface shall be free from tack. 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.

c) Cooling Time

The cooling time shall not exceed a characteristic straight line curve, the lower limits of which are two minutes at 50° F, the upper limits of which are 15 minutes at 90° F, both temperatures measured at a maximum relative humidity of 70%. After application and proper cooling time, the material shall show no appreciable deformation or discoloration under local traffic conditions, ambient air, or road temperatures ranging from 0° to 140° F.

d) Color

White reflectorized thermoplastic material shall have a pigment containing from 8% to 10% 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 (Federal Test Method Standard 141 Method 4252). The material shall not change its color and brightness characteristics after prolonged sunlight exposure.

e) Reflectorization

During manufacture, reflectorizing glass spheres shall be mixed into the material to the extent of not less than 20%, nor more than 50%. by weight of material. Glass spheres shall also be automatically applied to the surface of the material at a uniform rate of a minimum of three pounds of glass spheres to every 100 square feet of line. The glass spheres shall be dropped onto the thermoplastic material while it is in a molten state immediately after it has been applied to the pavement.

III. Physical Requirements

a) Color

White: Initially, the white shall be, as demonstrated by a standard color difference meter such as the Gardner Color Difference Meter standard, not greater than the following:

Reflectance (RD)	70% minimum
Redness - Greenness	(a) 0 + or - 5%
Yellowness - Blueness	(b) 0 + or - 10%

Yellow: Initially the yellow shall be equal to standard color chips, using Federal Test Method Standard 141 Method 4252.

b) Color Retention

The retention of the initial color may be determined by testing. Specimens shall be prepared and placed in a carbon-arc weatherometer for accelerated exposure. After 200 hours of exposure, specimens shall show no perceptible color change when compared visually with an unexposed specimen.

c) Water Absorption

Materials shall have no more than 0.5% by weight of retained water when tested by ASTM Designation: D 570, "Water Absorption of Plastics." Procedure 6.1.

d) Softening Point

Materials shall have a softening point of not less than 194° F, as determined by ASTM Designation: E 28, "Method of Test for Softening Point by Ring and Ball Apparatus."

e) Specific Gravity

Specific Gravity of the thermoplastic compound at 77° F shall be from 1.8 to 2.5.

f) Impact Resistance

The impact resistance shall be not less than ten inch/pounds at 77° F after the material has been heated for four hours at 400° F and cast at 125 mils thick and 4 inches wide over a 6"x12"x2" concrete block. The cured thermoplastic line shall be subjected to a vertical impact resistance apparatus with a 5/8-inch diameter head. The material shall not chip or flake or lose adhesion to the concrete block after testing.

g) Bond Strength

When two 2"x3-1/2"x7" concrete blocks are bonded together on the 3-1/2"x7" faces with a 1/8-inch layer of the thermoplastic traffic line material with any binder-sealer that is to be used in field application, the bond strength shall be not less than 50 pounds per square inch. (The concrete blocks are preheated to 200° F.)

h) Identation Resistance

The reading of the Shore Durometer, Type A2, as described in ASTM Designation: D 1706, after 15 seconds and using a two-pound weight, 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
115° F	65 + 2
77° F	95 + 2

IV. Properties of Glass Spheres for Reflectorization

a) Refraction Index

The glass spheres used in the formulation shall have a refractive index of not less than 1.50 when tested by the liquid immersion method at 75° F. At least 70% by count shall be water-white true spheres, free from air inclusions.

b) Gradation

A sieve analysis of glass spheres shall be made in accordance with ASTM Designation: D 1214 and shall meet the following gradation requirements.

For compounding in the manufacture of the thermoplastic material:

U. S. Sieve No.	Percent Passing
40	80 to 100
80	0 to 10

For application on the molten thermoplastic material:

U. S. Sieve No.	Percent Passing
20	90 to 100
80	0 to 10

c) Chemical Resistance

The glass spheres shall withstand immersion in water and acids without undergoing noticeable corrosion or etching and shall be neither darkened nor otherwise noticeably decomposed by sulfides. The tests for chemical resistance shall consist of one-hour immersion in water and in solutions of corrosive agents, followed by microscopic inspection. A 3- to 5-gram portion of the sample shall be placed in each of three pyrex-glass beakers of porcelain dishes; one sample shall be covered with a distilled water, one with 3N solution of sulfuric acid, and the other with a 50% solution of sodium sulfide. After one hour of immersion, the glass spheres of each sample shall be examined microscopically for evidence of darkening and frosting.

d) Packaging

Glass spheres used in drop-on application to the molten stripe shall be shipped in bags of multi-ply paper or burlap with a polyethylene liner. The bags shall be strong enough to permit multiple handlings without damage and sufficiently water resistant so that the spheres will not become wet or caked in transit.

V. Application

a) Equipment

The material shall be applied to the pavement by the extrusion method only: wherein one side of the extrusion shaping die is the pavement, and the other sides are formed by suitable equipment for heating and controlling the flow of the material. The equipment shall be constructed to provide continuous mixing and agitation of material. Conveying parts of the equipment between the main material reservoir and the discharge mechanism shall be so constructed as to prevent accumulation and clogging. All equipment parts 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 shall maintain the material at the molten temperature. The equipment shall be so constructed as to assure continuous uniformity in the dimensions of the stripe. The lateral cross-section thickness of the material on the pavement shall be no less than 3/32 inch and no more than 1/8 inch measured as an average in any 3-foot length for lane lines, cross lines and symbols. The extrusion applicator shall produce clearly and sharply defined lines and provide means for cleanly cutting off square stripe ends and shall provide a method of applying "skip lines." The use of pans, aprons or similar appliances will not be permitted under this specification. The equipment shall be so constructed as to produce 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 at a controlled rate of flow upon the installed line. The glass spheres dispenser shall be equipped with an automatic cut-off control synchronized with the cut-off of the thermoplastic material. Special kettles to hold a minimum of 1,000 pounds of material shall be provided for melting and heating the thermoplastic material. The kettle must be equipped with automatic thermoplastic control devices so that the heating can be done by controlled heat transfer liquid rather than direct flame, so as to provide positive temperature control and prevent overheating of the material. The applicator and kettle must be so equipped and arranged as to satisfy the requirements of the National Board of Fire Underwriters. The applicator 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 lengthy main roadway installations shall consist of a motorized mobile unit capable of installing traffic stripes, applying the stripe either to the left or right of the applicating unit so that only one lane of traffic will be occupied during installation.

b) Installation Techniques

The material shall be installed in variable specified widths from 2 to 18 inches. The contractor shall remove all dirt, grease and existing markings. Finished lines shall have well defined edges and be free of waviness. On concrete pavement surfaces a binder-sealer material shall be applied to the road surface prior to the actual thermoplastic installation. All dust, debris and other foreign matter --and existing markings--shall be removed from the road surface immediately prior to the installation of the material. The binder-sealer material will form, when sprayed, a continuous film over the pavement surface. To insure optimum adhesion, the thermoplastic material shall be installed in a melted state at a temperature of 375° F to 425° F.

The minimum thickness of thermoplastic lines as viewed from a lateral cross-section shall be not less than 3/32 inch at the edge and not more than 1/8 inch at the center for cross lines, stop lines and lane lines. Measurements shall be taken as an average throughout any 36-inch section of the line. Longitudinal lines shall be off-set one inch from construction joints of Portland cement concrete pavement.

VI. Warranty

The thermoplastic pavement marking material furnished and installed by contract under this specification shall be guaranteed by the contractor against failure due to poor adhesion resulting from defective materials or methods of application. For non-defective pavement surfaces the contractor shall guarantee to replace or renew, without cost to the state, that part of the pavement markings installed which have not remained to perform useful service as follows:

> Lane Lines, Edge Lines and Center Lines.
> Ninety percent of a unit for one year, 80% of a unit for two years, and 60% of a unit for three years. (A "unit" is defined as any length of highway having installed thereon 2,000 linear feet of line of specified width in any combination or pattern.)
>
> The replacement material installed under this guarantee shall be guaranteed the same as the original material, from the date of the original installation.

Note: The intent is not to extend the original warranty period.

VII. Packaging

The material shall be delivered in containers of sufficient strength to permit normal handling during shipment and transportation on the job without loss of material. Each container shall weigh no less than 24 pounds or more than 52 pounds and shall be clearly and adequately marked to indicate the color of the material, the process batch number, the name of the manufacturer, and the date of manufacture (month and year).