PAVEMENT MARKING

STUDENT MANUAL

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FUNCTIONS AND LIMITATIONS

Pavement markings provide traffic control and positive guidance. In some instances, they supplement the regulations or warnings of other devices such as traffic signs or signals. In other instances, they are used alone, producing results that cannot be obtained by any other device. Accordingly, markings effectively convey certain regulations and warnings that may not otherwise be clearly understandable.

However, pavement markings have definite limitations. They may be obscured by snow, may not be clearly visible when wet, and may not be very durable when subjected to heavy traffic. Despite these limitations, under favorable conditions, pavement markings can convey warnings or information to the driver without diverting his/her attention from the roadway.

STANDARD APPLICATIONS

Each standard marking shall only be used to convey the prescribed meaning in the Manual on Uniform Traffic Control Devices (MUTCD). Before any new highway, roadway detour, or temporary route is opened to traffic, all necessary markings shall be in place.

Markings no longer applicable, including pre-marking, which may confuse the driver, shall be removed or obliterated as soon as possible. Road conditions and restrictions may require other markings. However, these markings should be removed or obliterated after the conditions improve or the restrictions are withdrawn. Also, all road markings shall be reflectorized.

Traffic authorities' ability to accommodate variable traffic conditions has become increasingly important. Accordingly, signs and signals that can display variable messages have been developed. However, using variable message displays can be more limited and confined than the flexible cones and posts. Hopefully, in the future, there will be more practical methods of conveying variable messages from markings. When necessary to implement variable message markings, extreme care shall be exercised to adhere to the principles set forth in the MUTCD.

COLORS

- Pavement markings shall conform to standard highway colors.
- Black is permitted for temporary obliteration.

GENERAL PRINCIPLES - LONGITUDINAL PAVEMENT MARKINGS

Longitudinal pavement markings shall conform to the following basic concepts:

- Yellow lines delineate the separation of opposing traffic flows or mark the left edge of the pavement on divided highways and one-way roads.
- White lines delineate the separation of traffic flows in the same direction or mark the right edge of the pavement.
- Broken lines are permissive.
- Solid lines are restrictive.
- The width of a line indicates the degree of emphasis.
- Double lines indicate maximum restrictions.
- Raised pavement markers serve as position guides, and may supplement other types of markings.

WIDTHS AND PATTERNS OF LONGITUDINAL LINES

The widths and patterns of longitudinal lines shall be as follows:

- A normal width line is 4 to 6 inches wide. (MUTCD, Section 3A.06)
- A wide line is at least twice the width of a normal line.
- A double line consists of two normal width lines separated by a 4 to 6 inch space. (MUTCD, Section 3A.06)

- A broken (standard skip) line is formed by segments and gaps, usually in a 1:3 ratio. On rural highways, a recommended standard is 10-foot segments and 30-foot gaps. (MUTCD, Section 3A.06)

- Short segments, normally 3 feet long, and gaps, normally 9 feet long, form an auxiliary skip line. (Modified MUTCD 3A.06)

- High Occupancy Vehicle (HOV) markings are specified by the appropriate government agency and may differ in pattern.

LONGITUDINAL LINES

The following examples illustrate the application of the principles and standards set forth in the previous sections.

- A normal, broken, white line is used to delineate lanes where travel is permitted in the same direction on both sides of the line. Its most frequent application is as a lane line for a multi-lane roadway.

- A normal, broken yellow line is used to delineate the left edge of a travel path where travel on the other side of the line is in the opposite direction. A frequent application is as a center-line of a two-lane, two-way roadway where overtaking and passing is permitted.

- A normal, solid, white line is used to delineate the edge of a path where travel in the same direction is permitted on both sides of the line, but crossing the line is discouraged, but not prohibited. It is also used to mark the right edge of the pavement. Frequently, this is used as a lane delineation line when approaching an intersection. A wide solid white line is used for emphasis when crossing requires unusual care. Frequently, it is used to delineate left or right turn lanes.

- A double solid white line is used to delineate a travel path where travel in the same direction is permitted on both sides of the line, but crossing the line is prohibited. It is frequently used before obstructions guiding the driver to pass on either side of the obstruction.

- A double line consisting of a normal, broken, yellow line and a normal, solid, yellow line delineates a separation between travel paths in opposite directions permitting traffic that is adjacent to the broken line to pass "with care" and prohibiting traffic adjacent to the solid line from passing. This is a one direction, no-passing marking. It is used on two-way, two- and three-lane roadways to regulate passing. It is also used to delineate the edges of a lane where travel in either direction is permitted as a part of a left-turn maneuver. To permit a left turn maneuver, the marking shall be placed with the solid lines on the outside and the dashed lines to the inside of the lane. Traffic adjacent to the solid line may only cross this marking during a left-turn maneuver.

- A double line consisting of two normal solid yellow lines delineates travel in opposite directions prohibiting passing in both directions. This is a two-direction, no-passing marking. Crossing this marking with care is permitted only when making a left turn. It is frequently used before an obstruction that must be passed on the right or to form a channelizing island separating traffic in opposite directions.

- A double, normal, broken yellow line delineates the edge of a lane where direction of travel periodically changes and the line serves as a centerline at some point. It is used for a reversible lane.

- A normal dotted line is used to delineate a line through an intersection or interchange area. It shall be the same color as the preceding line.

- A solid yellow line delineates the left edge of a travel path to restrict passing on the left or to delineate the left edge of each roadway of divided streets or highways, one-way roadways, and ramps in the same direction of travel.

TRANSVERSE MARKINGS

Transverse markings, which include shoulder markings, word and symbol markings, stop lines, crosswalk lines, speed measurement markings and parking space markings shall be white. However, transverse median markings shall be yellow. Blue and red are permitted under certain circumstances.

Because pavement markings are viewed from a low angle, transverse lines shall be proportioned to give visibility equal to that of longitudinal lines. Pavement marking letters, numerals, and symbols shall adhere to the Standard Alphabets for Highway Signs and Pavement Markings, in the MUTCD.

Note: The MUTCD can be downloaded from the FHWA website to supplement this manual: http://mutcd.fhwa.dot.gov

SECTION II

PAVEMENT MARKING MATERIALS

CHAPTER 2 REFLECTIVE GLASS BEADS

OBJECTIVES

1) Background
2) Retroreflectivity
3) How Glass Beads Work
4) Manufacturing Methods
5) Bead Properties
6) Evaluation of Glass Beads
7) Application of Glass Beads
8) Evaluation of Glass Bead Application
9) Evaluation of Retroreflectivity
10) New Materials

BACKGROUND

Highway accidents and deaths began with the advent of the wheel. However, man has always been able to solve his problems. In fact, early highway safety methods were truly ingenious. Records show that in Rome, before Christ, recessed bricks or rocks were used in the center of the roads to keep chariots on their own side of the road. Also, over 350 years ago, light-colored rocks imbedded in the center of the roads in Mexico were used for the same purpose. Thus, markings have been used for many years to increase highway safety.

The first striping in the United States is credited to Edward Hines, a road commissioner in Wayne County, Michigan, back in the early 1900's. In 1921, a black stripe was painted by hand for one block of Madison, Wisconsin, because the Highway Commission concluded that the stripe kept traffic on the right side of the road. The obvious benefits of this centerline stripe were eventually recognized, and the idea spread.

In the early days, a substantial problem was how to get the stripe on the road. One of the first striping machines consisted of a wheelbarrow frame, a five-gallon tank, and a canvas-wrapped wheel with white paint in the tank channeled to drop onto the wheel. This allowed a man pushing the wheelbarrow to paint a white line down the center of the road. Using white paint improved the visibility of the line and helped channel traffic. However, at night the lines were hard to see and were found to wear rapidly.

The May 1924 issue of *Engineering News - Record* reported that the Ohio Highway Department placed white bricks in the center of a brick road at a cost of $185 per lane mile. Brass cups or brass circles were also used in an attempt to find a material that was easy to see and would have better wearability. Radioactive ingredients were also mixed with traffic paint to try and get a better line. This idea of using reflective beads became widely known in the late 1930's when the *Canadian Engineer* published a paper on "Luminous Marking for Highways." This article stated that "good visibility obtained and also the high abrasion resistance of the final product, made use of glass spheres advantageous."

In the early 1940's, during World War II, reflective beaded lines were used on highways to expedite traffic during blackouts. World War II was largely responsible for the widespread acceptance of beads to provide nighttime delineation due to the blackout condition imposed.

In 1942, *Engineering News - Record* wrote, "Paint surfaced with reflective beads has been found superior to any other type painted pavement marking. Five hundred miles of this type have been laid in Philadelphia and found to be very satisfactory. Although glass-beaded paint costs more, experience shows that it wears four to five times as long." In the early 1940's, it cost about three times as much to put down a beaded line as it did to put down a standard non-reflectorized pavement marking. Since that time, advances in technology in the reflectorized paint field have brought the price down significantly. However, even when reflectorized paint was first introduced, the greater durability of the paint line made the reflectorized paint more cost effective. Adding reflective beads made such an improvement in the traffic lines that a reflectorized line became the standard. Today, we use both reflectorized center and edge lines for greater safety. Figures 2.1 and 2.2 illustrate the difference between using pavement markings with and without reflective beads.

Figure 2.1
Pavement markings with reflective beads at night

Figure 2.2
Pavement markings without reflective beads at night

RETROREFLECTIVITY

Using beaded lines for nighttime reflectivity is now accepted worldwide. The advantages of using reflective beads are apparent when driving on a rural road at night. Added benefits of reflective beads are to protect marking material from tracking and to improve durability. However, during the day, a non-beaded paint line will appear richer and a more uniform color. However, this is misleading because the non-beaded paint line may not be visible at night.

If an engineer made the decision based only on the daylight evaluation, he/she would probably select the unbeaded line. If the same engineer evaluated these lines at night, he/she would undoubtedly select the beaded line.

Unbeaded paint lines will reflect light randomly in all directions. When round reflective beads are added, light is reflected directly to the source of the light. In industry, this is called retroreflectivity. The following illustrations demonstrate this.

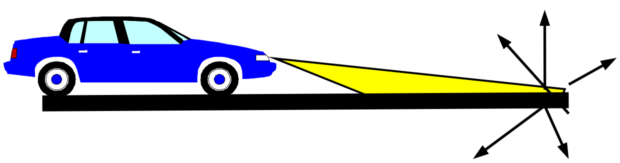

Figure 2.3
Roadway with unbeaded markings

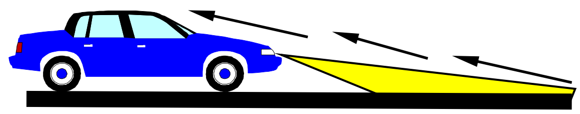

Figure 2.4
Roadway with beaded markings

In Figure 2.3 the light rays from an automobile's headlights illuminate a surface that does not retro-reflect. The light shining on the road, or a non-beaded line, is reflected in all directions. Only a very small amount is reflected directly back to the driver.

The beaded line illustrated in Figure 2.4 produces a much greater quantity of light reflecting directly back into the driver's eyes. Therefore, the driver sees the line better.

HOW GLASS BEADS WORK

Refractive Index of Glass

When light strikes a bead it is refracted and reflected. Refraction is the bending of the light. Refraction is observed when a pencil is dropped into a half filled glass of water; the pencil appears bent.

Reflective beads' ability to bend light is measured by its index of refraction, which is a ratio of the sine of the angle of incidence to that of the refraction.

The retroreflectivity of glass beads is better explained by examining the path of light as it enters a single bead in the paint (Figure 2.5). There are actually millions of tiny beads in each mile of beaded line that must perform this principle.

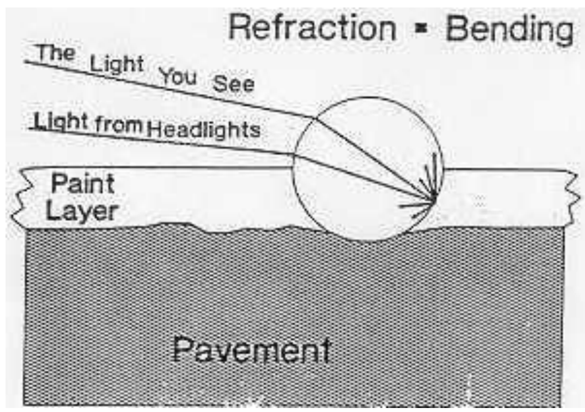

Figure 2.5
How beads retroreflect light

As the headlight beam enters the bead, it is bent or refracted downward. This beam then shines on the back surface of the bead, which is on top of the paint, thermoplastic, etc. It works a lot like a mirror. If the paint were not present, the light would continue through the bead and bounce in several directions. This is one reason for proper bead embedment depth (explained below). The light is bent (refracted) downward by the curved surface of the bead to a point below where the bead is embedded in the paint. Thus, when light is reflected off the paint at the back of the bead, a large portion of that light is reflected through the bead and refracted back toward your eyes.

The amount of refraction of light is characteristic of the glass itself and is known as the refractive index (R.I.) of the glass or bead. The refractive index of the glass is dependent upon the chemical and physical make-up of the glass material. Various types of beads have different indices of refraction and cause different amounts of light to be retroreflected.

Water has an index of refraction of 1.33, while the typical bead made with soda glass has a refractive index of 1.50. Beads used in the pavement marking industry are available in refractive indexes of 1.50, 1.65 and 1.90. The highest refractive material is 1.90 and is a very expensive bead to produce. Also, its durability is not as good as the soda glass type. Beads with a refractive index of 1.90 are generally called, "airport beads," since this type of bead is used to mark runways at airports.

Glass Bead Embedment

Retroreflectivity is dependent upon the embedment depth of the bead in the pavement marking material. Optimum embedment of reflective beads is 50-60% assuring optimum retroreflectivity. Embedment of less than 50% may affect the longevity of the beads. Increasing embedment beyond 60% significantly decreases the amount of light that can be directed back to the driver. A bead totally embedded in the binder is non-retroreflective because no light enters the bead. In summary, the amount of glass bead embedment will affect the retroreflectivity and the line durability. For optimum retroreflectivity and durability, a bead should be embedded at 50-60% of its diameter. Not all beads will be embedded 50-60%. Some beads will be completely buried and others will be embedded less than 50%.

A new line will generally have 70% of all the beads completely buried in the paint or other marking material. The remaining 30% will be embedded in the surface and exposed to the headlights. Figure 2.6 shows beads that were sprayed too late behind the paint operation. The beads in this picture are insufficiently embedded. Figures 2.7a and 2.7b show beads embedded in a paint line that is too thin. Figure 2.8 illustrates proper bead embedment.

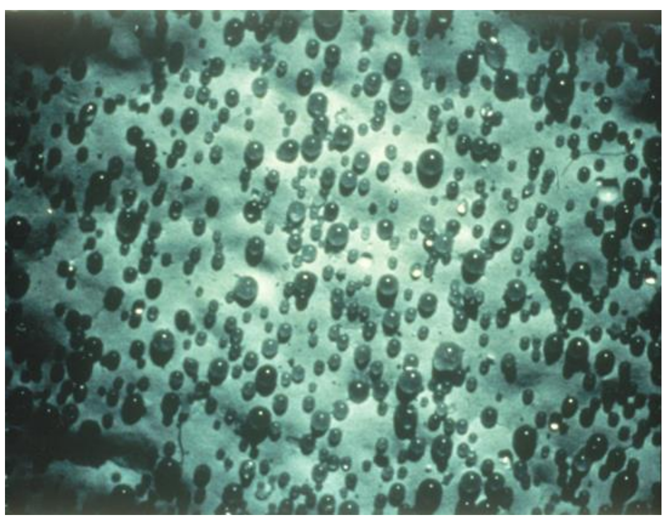

Figure 2.6
Improper bead embedment

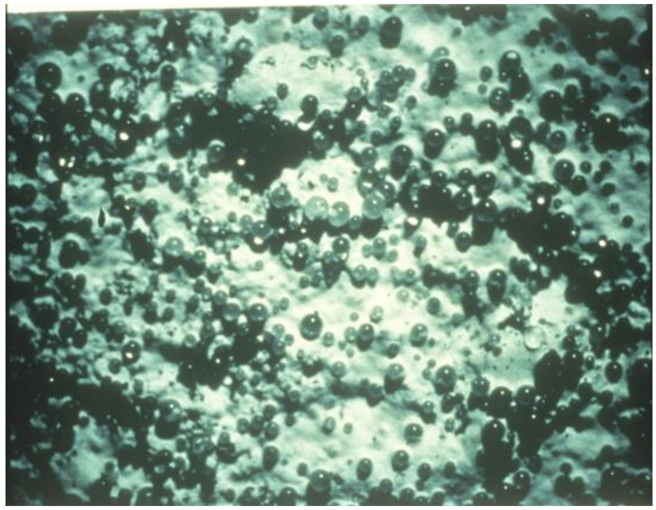

Figure 2.7a
Top view of reflective beads applied to a layer of paint that is too thin

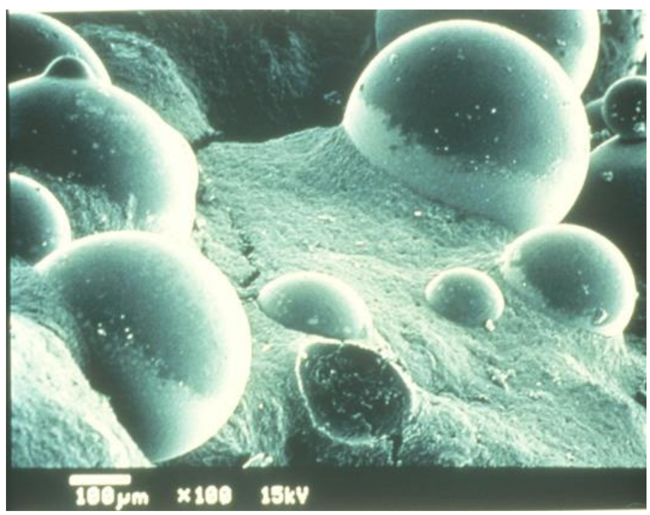

Figure 2.7b
Magnified view of reflective beads applied to a layer of paint that is too thin

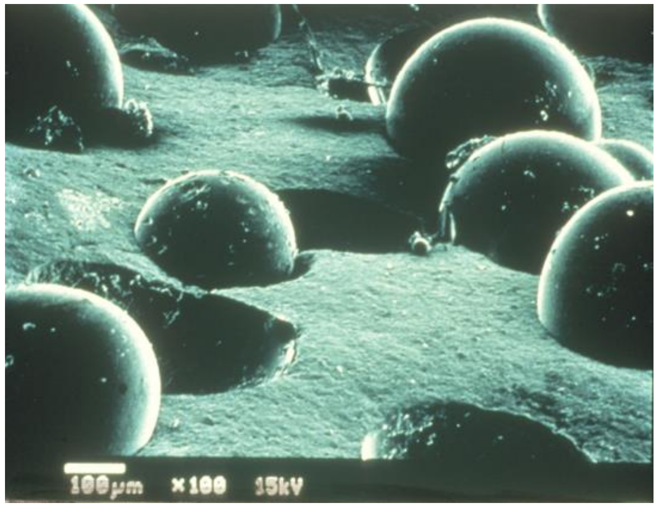

Figure 2.8
Magnified view of reflective beads at proper embedment depth

Figure 2.9 illustrates the embedment of various sizes of beads in a 15 mil wet line. Figure 2.10 illustrates the embedment of the same beads after the line has dried to 8 mils. Notice the embedment depth of the 40-50 mesh beads in each line. These figures illustrate how 40-50 mesh beads end up at the proper embedment depth when applied to a 15 mil wet line that dries to 8 mils.


mesh size

Figure 2.9
Beads in a 15 mil wet line


mesh size

Figure 2.10
Beads in an 8 mil dry line

MANUFACTURING METHODS

There are two basic manufacturing methods to make beads: the direct method and the indirect method. In the direct method, liquefied (molten) glass is sprayed and atomized into spheres similar to how water will form droplets when it is sprayed from the nozzle of a garden hose. As the molten glass is sprayed or forced out of the bead making tank, it is suspended as spherical droplets, which are cooled, collected, and then sifted through specifically - designed grading screens. This method, generally used for special formulations, can be used for 1.65 and 1.90 R.I. beads because their rheology will change from a molten state to a hardened bead.

The indirect method is the most commonly employed process for 1.50 R.I.. In this method, a selected material (either new or reclaimed cullet) is pulverized into glass powder. This powder is then poured, sprayed, or sprinkled into a large three- to four- story furnace (Figure 2.11). The individual particles are blown through several flames until they soften and take the shape of spheres. These spherical droplets are cooled in the top half of the furnace and are then collected and sifted through specifically designed grading screens. Material from either method can be mixed to provide the necessary gradations to meet desired specification limits. After manufacturing, these highway beads are bagged and stocked for shipment.

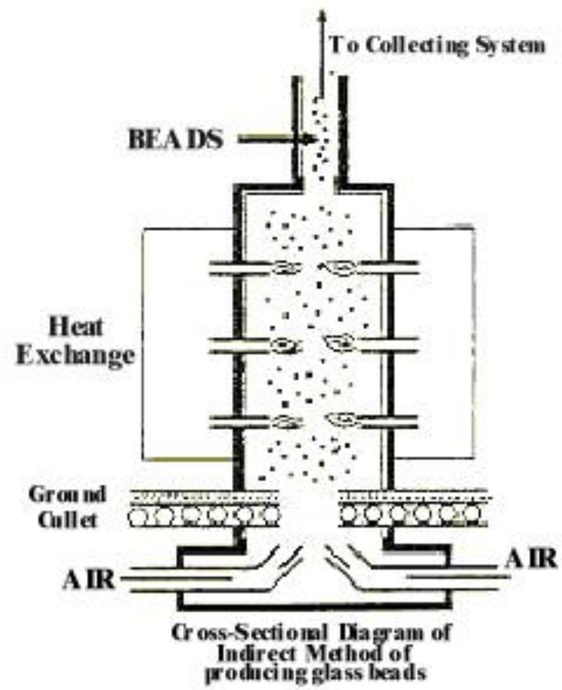

Figure 2.11
Indirect method for manufacturing glass beads

BEAD PROPERTIES

The size range or gradation and the roundness of the beads have a definite influence on the initial and long-term retroreflectivity of the pavement markings. Bead coatings will affect bead handling and adhesion to the pavement marking material. Numerous evaluations and years of experience have resulted in the selection of bead sizes for optimal performance under normal traffic conditions.

<u>Size or Gradation</u>

The 20 to 80 mesh bead sizes are generally recommended based on the following assumptions:

- Striping equipment does not apply a uniform paint line because of uneven pavement and possible spray/atomization problems.
- The paint line is applied wet and thickness varies when dried.
- For optimum durability and visibility, a sphere should be embedded 50% to 60% of its diameter.
- The resulting reflectorized line will give the best possible retroreflectivity under all conditions.

Note: Figure 2.12 illustrates the typical sizes of glass beads.

Typical Highway Gradation

U.S Sieve	Microns	Inches
80	180	.0070
50	300	.0117
30	600	.0234
20	850	.0334

Range For Larger Beads Depending On Binder

U.S Sieve	Microns	Inches
16	1180	.0469
14	1400	.0555
12	1700	.0661

Figure 2.12
Relative bead size comparison

<u>Roundness</u>

In order to be retroreflective, beads must be round. Only round beads can reflect light back toward the light source.

When standard beads are specified, they shall conform to AASHTO M247 or government agency specifications and must have a minimum percentage of round beads. Beads shall be smooth and spherically shaped.

While the manufacturing process generally produces round glass beads, a percentage of the beads are not round. Some glass beads take on an oval or "football" appearance. Also, some beads adhere to each other in the solidifying process.

Bead Coatings

Reflective beads can be effective without any coatings. However, in some humid areas it is difficult to apply the beads because they clump in the bead hopper or tank of the striping machines. To overcome this problem, a moisture- proof coating is applied to the beads allowing them to remain free flowing under all striping conditions. This coating alleviates problems during application, but was not designed to improve wet weather visibility. The moisture proof coating allows the beads to be stored, handled and applied without clumping. The proper coating will also enhance the adhesion between the bead surface and the pavement marking material. The coating that is generally used is a thermosetting silicone resin. Each manufacturer has their own system to make the beads flow without clumping. Some may use silicone oils or add inorganic particles such as china clay.

EVALUATION OF GLASS BEADS

Before glass beads are approved, they must be tested to ensure they meet the specifications for refractive index, size, and roundness.

Refractive Index Evaluation

To determine the refractive index of reflective beads, the beads are treated as a pigment. Most pigments are tested using the liquid immersion method at a temperature of 77 °F. To determine the refractive index of beads, refer to government agency specifications.

Evaluation of Bead Size

To evaluate the bead size, the beads are hand sieved through standard sieves starting with the largest opening and progressing to the smallest opening sieve. The reflective beads are weighed on each sieve and the percent that passes through each sieve is calculated. Refer to Figure 2.13 for bead size guidelines.

SIEVE DESIGNATION	MASS PERCENT PASSING	
U.S. Sieve Sizes	Type I	Type II
20	100	-
30	75-95	100
40	-	90-100
50	12-35	50-75
80	-	0.5
100	0.5	-

Figure 2.13
Gradation of glass beads

<u>Evaluation of Roundness</u>

To evaluate roundness, the controlled vibration of a glass plate held at a fixed slope mechanically separates the reflective beads. The round reflective spheres will roll down the slope while the irregularly shaped particles vibrate to the top. After testing the complete sample, the percent of round beads is calculated by weighing the quantity of round beads that have rolled down the glass slope versus the quantity of irregular shaped beads that have vibrated up the glass slope.

Another method used to evaluate bead roundness is visual evaluation using magnification where beads are adhered to a transparent adhesive surface and viewed under magnification. This method is normally used to evaluate larger beads.

APPLICATION OF GLASS BEADS

The proper placement of beads and pavement marking material on a road surface is the most important step in obtaining a durable reflective line. During this process, all variables must be controlled. The following must be considered:

<u>Liquid Pavement Markings</u>

Most highway marking material is applied on Hot Mix Asphalt (HMA) or Portland Cement Concrete (PCC). The major problem with these surfaces is obtaining a lasting bond between the binder and the substrate. This bond may be affected by dirt, substrate texture, the chemical or mechanical properties of the surface, concrete latency, curing compounds and road surface oils in new HMA pavement. The presence of residue, expansion joints, cracks and sealants can adversely affect the performance of the line.

<u>Binders</u>

The resin in the marking material (paint, thermoplastic, etc.) is the "glue" adhering the beads to the road surface. The pigment/binder thickness is an important variable closely related to beads retainment and the quantity of beads used. The type and quantity of pigmentation and filler play an important role in the retroreflectivity of the beads as well as the daylight appearance of the line. After the best striping materials are selected, the three most important variables involved in the application of lines are the equipment, operator skill, and ambient conditions.

Equipment

The application equipment must be in good condition and properly designed for the type of product it is to apply. The development and use of computer-aided delivery systems have helped provide adequate means to accurately control film thickness and bead application rates.

Operator Skill

Operator skill is essential to achieve reasonable control over "liquid markings" and bead application**.** This applies to both the driver of the vehicle and the operator of the application controls.

Ambient Conditions

Pavement markings shall only be applied when the ambient conditions will give the best results. When striping must be done under more adverse conditions, the results may be affected.

EVALUATION OF GLASS BEAD APPLICATION

The visual evaluation of a newly applied pavement marking line is an important part of the quality control process. Proper bead distribution and depth are critical to ensure a durable and retroreflective line. Since visual evaluation of glass bead application can be subjective, the following illustrations and descriptions are provided to demonstrate good and bad bead distribution. Figure 2.14 is a representation of a good stripe demonstrating uniform distribution of glass beads, whereas Figure 2.15 shows a stripe with good distribution but not enough glass beads.

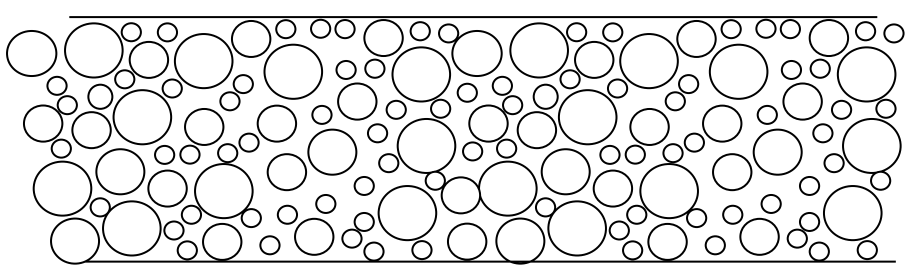

Figure 2.14
Representation of good bead distribution

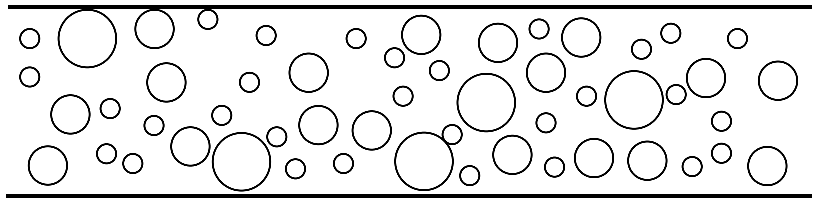

Figure 2.15
Too few beads

Figure 2.16 shows striping material that is too thick in the center and too thin on the edges. The beads in the center of the stripe are covered with material and are non-reflective. The edges may be reflective but because of the thinner material film, not as durable. This may be due to improper atomizing pressure and/or improper material pressure and/or improper material viscosity.

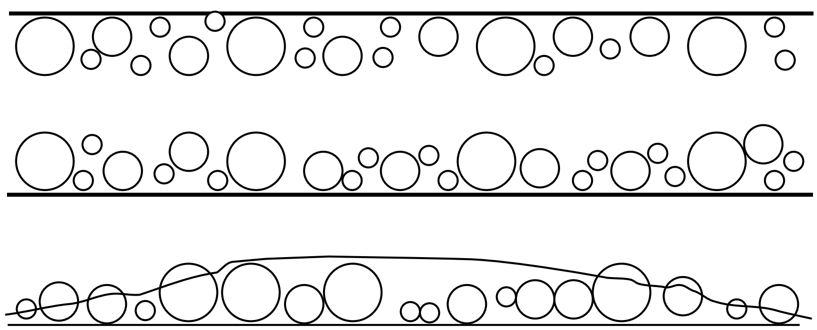

Figure 2.16
A contoured line

Figure 2.17 illustrates poor distribution of beads. An improperly placed bead dispenser or possibly a windy day may result in the distribution of beads on only part of the stripe.

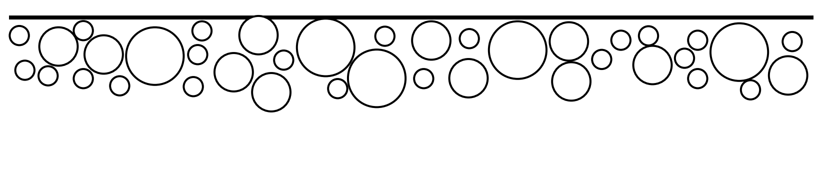

Figure 2.17
Beads on only one portion of the line

Problems with inconsistent air pressure or pulsed air pressure may lead to pulsed or sporadic application of beads as illustrated in Figure 2.18.

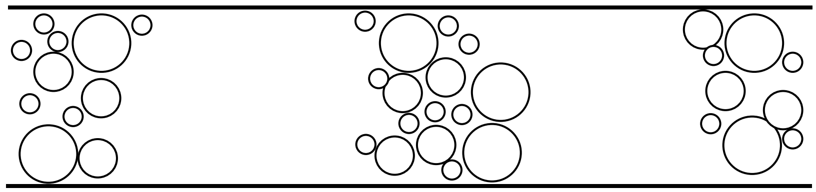

Figure 2.18
Line from a pulsating bead gun

EVALUATION OF RETROREFLECTIVITY

While other aspects of appearance and durability are important to determine the useful life of pavement markings, those markings are only useful if they can be seen in all conditions, especially at nighttime. Retroreflectivity testing has improved the performance of pavement markings.

Retroreflectivity can be assessed either visually at night or by the use of retroreflectance meters such as the Mirolux-12, Ecolux, Gamma/ART Retrolux-1500, or the Delta LTL-2000. Currently in the United States, 15- and 30-meter geometry instruments, as well as mobile equipment technologies are used.

The color of the pavement marking may affect the results of the retroreflective instruments. For example, if a non-leaded yellow paint line begins to deteriorate from UV radiation (i.e.- get lighter in color) but has no bead loss from the initial application, the reflectometer values may increase.

In summary, **retroreflectivity** and **durability** are a function of the following parameters:

- The refractive index of the glass bead material
- Gradation or size of the glass beads
- Roundness of the beads
- The coating on the beads
- The embedment of the beads in the material
- The distribution of glass beads in the pavement material
- The number of exposed beads on the marking surface
- The relationship between the diameter of the beads and the striping material thickness

The first four items are controllable manufacturing items. These can be specified and tested for minimum requirements. The last four items are related to the application of materials. Even if the first four items are strictly adhered to, either a bad application of binder material or a bad application of beads will negate the quality of the ingredients and result in a non-durable and/or non-retroreflective pavement marking.

NEW MATERIALS

Advances in striping materials (i.e. higher solids, better reactive polymers, etc.) as well as advances in adherence type coatings on reflective beads allow larger reflective beads to be used. These larger reflective beads provide better wet night retroreflective performance. Standard reflective beads, as previously described, may have their retroreflectivity "turned off" by a thin film of water. The new larger reflective beads stick up above a water film and continue to retroreflect headlights during rain. However, the larger beads are more susceptible to snow plow damage.

Figure 2.19 is a troubleshooting guide for bead application problems.

REFLECTIVE BEAD APPLICATION TROUBLESHOOTING			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Beads on one side	• Bead gun out of alignment • Clogged bead gun	• Poor night visibility	• Adjust alignment of gun cap • Rebuild gun
Excessive bead use	• Worn gun needle, seat and orifice • Excessive glass bead pressure	• Supply problems	• Rebuild gun • Decrease pressure
Beads in middle of line	• Bead tank pressure too low • Bead gun "off" and "on" control screw not adjusted • Bead gun cap out of alignment • Too big of a bead gun tip	• Poor night visibility	• Increase Pressure • Adjust control screw • Align cap deflector • Change to a smaller tip
All beads buried	• Bead gun too close to paint • Bead gun angle too shallow • Excessive paint millage	• Poor night visibility	• Re-align bead gun • Adjust angle of bead gun • Check wet millage thickness
All beads on top of line	• Bead gun too far from paint gun	• Loss of durability • Initial very bright line	• Re-align bead gun
Pulsed bead application	• Bead tank pressure inadequate	• Violates standard • Loss of effectiveness	• Raise tank pressure • Rebuild applicator to increase pressure
Excessive amount of beads on road beside line	• Too much overlap of bead pattern on line pattern	• Loss of reflectivity	• Move bead gun closer to roadway

Figure 2.19
Reflective bead troubleshooting chart

CHAPTER 3 TRAFFIC PAINT

OBJECTIVES

1) Traffic Paint

2) Components

3) Reflective Beads

4) Characteristics of Waterborne Paint

5) Characteristics of Solvent Borne Paint

6) Application Considerations

TRAFFIC PAINT

Traffic paint is a thin layer of blended material. This chapter will describe waterborne traffic paint and solvent borne traffic paint. Reflective beads are added to the surface of the paint during application to produce nighttime retroreflectivity.

COMPONENTS

Paint is mainly composed of finely ground pigments that are mixed into a resin or binder system. Then various ingredients and additives are incorporated for certain desired properties. A liquid (water or solvent) is added to the mixture to produce a material that is pliable by application equipment. All of the ingredients/components in traffic paint are added specifically for one or more of the following functions: aiding the manufacturing process, increasing storage time in containers, easing application, and increasing durability once the paint has been applied.

Prime Pigments

Prime pigments are used to impart chemical properties such as UV stability, or physical properties such as color and hiding. Hiding is the ability of a paint to cover or block out the surface (substrate) beneath it. Titanium dioxide is typically used to make a white color. It is the primary pigment that gives traffic paint good hiding power.

Lead chromate was typically used to make a yellow color. However, due to health concerns with lead chromate pigments, organic pigments are now being used as a substitute for the lead chromate. Some types of pigments can be used interchangeably between solvent borne and waterborne traffic paint.

Extender Pigments

Once the necessary amount of prime pigment is added for hiding, less expensive extender pigments or fillers are used to bring the pigment level up to the required point. Extender pigments not only reduce cost, they give paint consistency, durability, permeability, and scrubability. These properties are very important when considering the harsh environment and abuses that traffic paint must withstand. The main types of extenders are aluminum silicate (china clay), calcium carbonate, calcium sulfate, and magnesium silicate.

Resins or Binders

The resin is the component that bonds the pigment and beads together. It also provides the adhesion to the road surface. The resin is the binder or glue in paint.

Waterborne paints typically use three types of resins. They are polyvinyl acetate latex, methylmethacrylate, or a one-hundred-percent acrylic resin. These materials are pre-reacted and put into solution using emulsifiers. These emulsions are materials that normally do not mix. Once the paint has been applied, it must allow the water to evaporate in order for the paint to "break" and adhere to the roadway. This settling is generally called coalescence. One-hundred-percent acrylics are used predominantly due to faster "no track" times and less heat needed during application.

Because of high humidity, waterborne paint will take longer to dry. Therefore, on low humidity days, waterborne paint will dry much faster. When there is less water in the air, the water can leave the film or evaporate much faster.

Solvent borne paints are typically linseed or soya oils and alkyd resins. These paints cure by solvent evaporation and the resin reacts with atmospheric oxygen to create a solid bond to the pigments, beads, and road surface. Some types of solvents used in these paints are naphtha, toluene, methanol, methylene chloride, and acetone. They are added to thin the paint out and make it easier to handle and spray.

Both waterborne and solvent borne paint resins have a critical value for the quantity of material that the resin can hold. This is called the critical-pvc pigment volume concentration. If this concentration is exceeded, the resin will not be able to bind the pigment and beads. This could also affect adhesion to the road surface.

Solvents

With waterborne paint, the water is more of a diluent rather than a solvent. It holds the resin emulsion in solution with the other components until the paint has been applied. Fast-dry waterborne paints may contain ammonia and/or methanol. Ammonia and methanol are Volatile Organic Compounds (VOCs). These VOCs accelerate the curing process throughout evaporation.

In solvent borne paints, the evaporation rate is very important. Because of this, they need to be tailored to leave the film at the right time. When solvents evaporate too fast, the surface can skim over and trap the rest of the solvents within the film. Most solvent blends keep the film open while solvents escape. That is why, as a general rule, just any solvent will not work.

Heat can be considered as a solvent for both waterborne and solvent borne traffic paint because it can be used to make paint more fluid and aid in evaporation.

Volatile Organic Compounds evaporate in the air. The Environmental Protection Agency (EPA) was mandated to establish VOC emission controls for "all field applied coatings." The Clean Air Act Amendment (CAAA) of 1990 designated these controls as "architectural coatings." This category is very broad ranging from interior house paints to heavy-duty industrial maintenance coatings. Different VOC limits were established according to the intended use of the coatings. Traffic Marking Coating VOC limits were set at 1.25lbs/gal. This is the result of the EPA's effort to reduce ozone, which is a significant ground level health hazard. A few materials, acetone and some special chlorinated solvents, have been declared exempt from these regulations because they don't increase ozone levels. From a 1990 nationwide baseline, the annual reduction of VOC emissions is 10,600 tons.

Additives

Additives are included in paint to help prevent problems. One example is an anti-foam agent, which keeps paint from foaming during the high-speed mixing process. Other additives help prevent the paint from freezing, settling, or skimming in the drum. Additives usually only make up 0.1 to 5 percent of the paint. Some have a single function and others may have multiple functions. For example, ammonia acts as an accelerator for drying and keeps the pH level up in waterborne paint while being stored. It is important to maintain the pH level at 9.5 or higher to ensure the latex remains suspended in solution.

REFLECTIVE BEADS

A separate gun adds reflective beads to the wet paint at the time of application. Some agencies may also require the premixing of beads into the paint prior to application.

Reflective beads for painted markings are typically applied under pressure. This is necessary for the beads to achieve the proper embedment in the paint before its fast drying nature causes it to form a surface skin. The bead supply tank is pressurized to force the beads through the system to the bead gun. Since the system is under pressure and is not loaded in a vacuum, moisture can condense inside the tank and cause clogging problems. For this reason, the manufacturer usually adds a moisture-proofing agent. Beads are typically applied at a minimum rate of 6 pounds of beads per gallon of paint.

Beads are generally shipped in 50-pound bags with 40 bags shrink-wrapped on a pallet. They may also be shipped in 2,000-pound boxes.

CHARACTERISTICS OF WATERBORNE PAINT

There are many disadvantages and advantages to using waterborne paints for pavement markings. One major disadvantage of waterborne paint is its sensitivity to temperature. Precautions must be taken to protect stored material from freezing and extreme heat. During application, latex paint is very sensitive to high humidity, which can drastically increase drying time. Conversely, low humidity creates a quicker drying time. Paint is also the least durable of all the markings and is not recommended for roadways with high traffic volumes.

Some advantages of waterborne paint are cost. It is the least expensive of all pavement markings. It can be applied at a faster rate than most other markings and under ideal conditions it can have a very fast dry time. Also, no solvents are needed for clean up. Fast dry waterborne paint will achieve its best drying times under perfect ambient conditions: daytime, sunny, 70ºF, low humidity and a breeze.

Some characteristics of waterborne paint are:

- Heat sensitivity
- Freezes easily
- Strong ammonia odor
- Humidity may affect drying times
- Can be flushed out with water and/or ammonia
- Generally not a hazardous waste for disposal - placarding not required (dependant on formulation)
- Reacts adversely to metals other than stainless steel
- Requires specially lined drums to prevent chemical reaction
- Can settle in the drum

CHARACTERISTICS OF SOLVENT BORNE PAINT

Some characteristics of solvent borne paint are:

- Humidity generally not an application problem
- Heat exchanger can be heated higher to assist in drying times
- Can film form at lower temperatures than waterborne
- Solvent blend critical to prevent skimming
- Requires placarding of vehicle
- Clean up flush material is hazardous waste

- Unused paint is hazardous waste for disposal purposes
- Can be very flammable
- Can easily settle in drum

Traffic paint is a one-component material that is generally shipped in 55-gallon drums with full open top lids. Traffic paint generally has a shelf life of one year. This information should appear on the shipping documents. Quality assurance tests may be performed to confirm that the original formulation is approved by the government agency and to verify the manufacturer's certification.

No paint forms a film well when applied at low temperatures.

APPLICATION CONSIDERATIONS

Traffic paint is applied by conventional or airless spraying.

Conventional

Conventional spraying uses air jets in the tip of the paint gun to break up, or atomize the paint. The tip then defines the shape of the spray to produce a properly applied line. The quantity of atomizing air needed to sufficiently break up the paint will depend to a large extent on the paints rheology, or flow characteristics.

The pressure needed to force the paint through the application system and out of the gun can vary from 60 to 140 psi, depending on the size of the plumbing and the type of spray gun used. This can be achieved using one of the following methods:

- In a pressure-pot system, the holding tank is pressurized to push the paint through the heat exchangers and lines to the gun for application.
- In a pumper system, the holding tank is not pressurized. A diaphragm pump is used to draw the paint from the tank and force it through the system and out to the gun.

Airless

In an airless system, the paint is forced out through an orifice in the tip of the gun at a high pressure. The size of the hole determines how much paint is applied and the angle of the inner surfaces of the tip determines the width. Unlike the conventional system, there is no air mixed with the paint in the gun. The pressure created by the pump mechanism explosively forces the paint through the gun tip breaking the paint up into very small particles. The primary method for altering the width and thickness of the applied line is to change the tip. Chapter 11 shows a picture of a long liner truck.

Additional factors must also be considered when applying traffic paint:

Material Temperature

The manufacturer's Product Data Sheets specifies the material application temperature ranges. Fast-dry (ammoniated), waterborne paint only needs enough heat to allow a good flow of material through the application system (generally in the range of 90 °F to 120 °F at the gun tip).

It is very important not to overheat the solvent or waterborne traffic paint because they can ignite. Overheating fast dry, waterborne paint can also "drive off" the methanol and ammonia creating longer dry times. These two additives act as driers to keep the paint film open, helping the water escape.

Ambient Conditions

Waterborne paint requires liquids to evaporate. This evaporation is dependent on the humidity (moisture in the air). Humid days will cause drying problems. Lower humidity and good air movement greatly improves waterborne materials drying. To achieve the optimal results, neither solvent nor waterborne traffic paint shall be applied below 50 °F (air temperature).

Pavement Surface Considerations

The pavement shall be free of dirt, oil, grease, laitance, curing compounds, and moisture. On new HMA pavements, paint may dissolve road oils and cause a discoloration of the line. This line should be repainted as soon as it has dried in order to achieve the proper color.

Quality Assurance Field Testing

Quality assurance field-testing shall be conducted in accordance with agency specifications.

Figure 3.1 is a troubleshooting guide for paint application problems.

PAINT APPLICATION TROUBLESHOOTING			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Excessive Thickness (overall)	• Paint tank pressure too high • Paint gun volume control (if present) open too wide • Pump pressure too high • Applicator speed too low	• Buried beads – poor initial nighttime retroreflectivity • Slow drying time – paint tracked by motorists • Paint won't cure properly – shortened life	• Reduce tank pressure • Adjust paint gun volume control • Reduce pump pressure • Increase speed

PAINT APPLICATION TROUBLESHOOTING –continued			
Excessive Thickness (middle of line)	• Paint tank pressure too high • Paint gun volume control (if present) open too wide • Pump pressure too high • Atomizing air pressure off or too low • Material buildup in paint gun tip and/or shroud	• Buried beads – poor initial nighttime retroreflectivity • Slow drying time – paint tracked by motorists • Paint won't cure properly – shortened life	• Reduce tank pressure • Adjust paint gun volume control • Reduce pump pressure • Increase atomizing air pressure • Clean tip and/or shroud
Excessive Thickness (along one side)	• Material buildup in paint gun tip and/or shroud • Clogged hole(s) in paint gun atomizing tip	• Buried beads – poor initial nighttime retroreflectivity • Slow drying time – paint tracked by motorists	• Clean paint tip and/or shroud • Clear clogged hole(s) in paint gun atomizing tip
Insufficient Thickness	• Paint tank pressure too low • Paint gun volume control (if present) not open enough • Pump pressure too low • Applicator speed too low • Atomizing pressure too high • Material buildup in paint gun tip and/or shroud • Material buildup in paint filter(s) and/or plumbing	• Poor line quality and/or shortened life • Beads won't adhere and/or poor or no nighttime retroreflectivity	• Increase tank pressure • Adjust paint gun volume control • Increase pump pressure • Decrease speed • Decrease atomizing air pressure • Clean paint gun tip and/or shroud • Clean paint filter(s) and/or plumbing
Wide Paint Line	• Paint gun set too high • Worn or damaged paint gun • Tip and/or shroud	• Line does not meet standards • Line has fuzzy edges	• Lower gun • Repair or replace tip and/or shroud
Narrow Paint Line	• Paint gun too low • Paint gun tip slot not at 90° angle to paint line • Clogged paint gun tip and /or shroud • Low air pressure in paint machine tire.	• Line does not meet standards • Not as visible as a full – width line (day or night)	• Raise paint gun • Reposition paint gun tip • Clean paint gun tip and/or shroud • Inflate tire

PAINT APPLICATION TROUBLESHOOTING-continued			
Uneven Paint Line (spotty)	• Atomizing air pressure too low • Paint tank pressure too low • Old paint (viscosity to high) • Loose paint gun tip and/or shroud • Insufficient heat • No shroud	• Poor appearance • Line has fuzzy edges • Slow drying time • Paint won't flow smoothly	• Increase atomizing air pressure • Increase material tank pressure • Rotate material stock • Secure paint gun tip and/or shroud • Increase heat (enough to get paint to flow evenly) • Install shroud

Figure 3.1

Paint application troubleshooting guide

<u>CHAPTER 4 LIQUID THERMOPLASTIC</u>

OBJECTIVES

1) Thermoplastic Material
2) Components
3) Material Characteristics
4) Application Methods
5) Application Considerations
6) Material Testing
7) Inspection and Quality Control

THERMOPLASTIC MATERIAL

Thermoplastic resin material has various uses, including being a durable pavement marking material. Thermoplastic is a blend of solid ingredients that become liquid when heated. It comes from the manufacturer intermixed with some reflective beads. When heated and properly agitated, the dry thermoplastic compound becomes a homogenized liquid. Reflective beads are intermixed and suspended in this liquid. Applied at the proper temperature, the thermoplastic melts into the upper surface of the HMA pavement forming a thermal bond. When applying thermoplastic to PCC, a primer/sealer from the thermoplastic manufacturer shall be used to ensure a proper bond to the surface.

Thermoplastic provides a visible, durable pavement marking because of its thickness and the use of intermixed and drop-on beads.

COMPONENTS

Thermoplastic resin marking is composed of pigment, reflective beads, filler, binder, and additives.

<u>Pigment</u>

Pigment is primarily used to impart color and to provide some chemical property, such as hiding or UV stability. Titanium dioxide is typically added to provide a white color and lead chromate or organic pigments are typically added to provide a yellow color. Because of environmental and health concerns, lead compounds in pavement marking material have been eliminated.

Reflective Beads

Thermoplastic is manufactured with a certain percentage of beads intermixed with the unmelted material. Additional beads are added to the surface of the applied line at a rate of 7-9 pounds per 100 square feet of marking material.

Filler

Fillers are pigments and are used to provide bulk. Once the necessary color and hiding has been obtained, fillers such as a mixture of calcium carbonate, sand, and other inert materials, are used to provide the needed volume adding durability, without the higher cost of the hiding pigments.

Binder

The binder is generally either hydrocarbon or alkyd. Generally, thermoplastic takes its name from the type of resin present. The hydrocarbon resin is made from petroleum-derived resins. The alkyd type is made from a naturally occurring resin. Both types of material are thermoplastic, they melt when heat is applied. Heat is used to form the initial shape and is also used to reform the shape. The material does not change chemically, but physically, during heating and application.

Additives

Additives like plasticizers are added to enhance rheological, or flow characteristics. Because the plasticizer can burn away, overheating and excessively reheating the thermoplastic can dramatically affect the quality of the line.

Solvent

There are no solvents in the traditional sense. The heating process transforms the thermoplastic material from a solid into a liquid.

MATERIAL CHARACTERISTICS

Two types of thermoplastics, hydrocarbon and alkyd, that exhibit different properties are used in pavement marking applications.

Hydrocarbon

- Relatively more heat stable than alkyd
- Exhibits predictable application properties
- Can break down under heavy oil drippings

Alkyd

- More resistant to deterioration from petroleum products
- Highly heat sensitive
- Requires great care during application

- May thicken if heated too long, causing it to become gummy and unstable, which will result in inconsistent markings

Manufacturers recommend that alkyd type material only be used if a new HMA surface will be marked in fewer than 10 days.

The manufacturer's application guidelines shall always be followed. Material formulations for extruded material are different than for spray material. The formulations are not generally interchangeable for each type of application. There are interchangeable formulations based on the method of application. It is important to verify that the proper and appropriate material is being used for the method of application.

Other factors that should be considered when using thermoplastics are packaging, shelf life, mixing materials, primers and priming, and material testing.

Packaging

Hydrocarbon and alkyd thermoplastic are available in either granular or block form.

The granular material is usually packaged in 50-pound bags. All other product components have been physically mixed together, but not heated. Manufacturers recommend heating this material no more than 3 times before discarding. The bags may be heat degradable.

The standard package for block material is 50-pound boxes. Supplied in this form, the components have already been heated to mix them together. Since it's been heated once during production, manufacturers recommend heating this material no more than 2 additional times before discarding.

Shelf Life

Thermoplastics have a shelf life of one year when stored inside at a temperature less than 100ºF. This must be considered when accepting the material for a project. Shipping documents are required to have the expiration or shelf life data printed on them.

Mixing Materials

Alkyd and hydrocarbon materials shall NOT be mixed. This applies to material in the melter equipment. If it is necessary to change from one type of material to the other, the melter shall be thoroughly cleaned first.

Primers and Priming

Primers are used as a "bridge" between thermoplastic and a surface where thermoplastic will not readily adhere. In other words, the primer bonds to the surface, and the thermoplastic bonds to the primer.

Some government agency specifications require the use of primer on all hydraulic cement concrete roadways. Manufacturers of thermoplastic recommend using a primer on HMA surfaces that are more than two years old, oxidized, and/or have aggregate exposed.

Primer must be applied to ensure adequate coverage, and must be allowed to cure according to manufacturer's instructions before applying thermoplastic. The primer must be from the same source as the thermoplastic material.

APPLICATION METHODS

There are three basic methods of applying liquid thermoplastic. These vary according to the type of device or gun that is used in applying the line to the roadway.

Spray Gun

This method of application is accepted in many states for all markings. It involves using a gun that is similar to that used in conventional paint application (i.e. the system is under pressure to deliver the material to the gun, and air is used to atomize the thermoplastic in the gun prior to its being forced out onto the roadway).

A major advantage of this method is that it is possible to go faster and cover rough surfaces with greater ease.

A major disadvantage of spraying is that going faster may result in heat loss of the material and may adversely affect the bond between the marking and the substrate. Also, the thickness of the applied line is more difficult to control than other application methods because it is directly affected by the speed of the applicator.

Screed / Extrusion Shoe

This method of application is typically used for legends, crosswalks, stop bars, etc. Thermoplastic material is forced through a die or shoe riding on the pavement surface. With gravity extrusion, the hot thermoplastic enters a trough or shoe that has a gate. The gate opening is set to produce the specified thickness as the material flows onto the pavement. Since the heat is maintained in the extrusion device, the bond remains consistent as long as the pavement surface is consistent. There are a number of extrusion devices that differ primarily in the inner workings of the shoe itself.

The major advantage of this method is that the material flows onto the pavement uniformly at the correct thickness. It's easy to get a well-defined line on most surfaces, and greater thicknesses can be achieved than with the spray method.

A major disadvantage is that on uneven surfaces, the material will flow out from the sides of the shoe, since the sides are used to contain the material. Also, the speed of application is much slower than that of the spray method.

Ribbon Gun

This method of application involves the using a gun that rides just above the pavement surface. Material is forced through the system and into the gun, and from there it flows onto the pavement. This method is NOT accepted by all agencies.

A major advantage of this method is that it produces sharp edges and is easier to mark rough surfaces.

However, a major disadvantage is that it may go on too fast, causing too much heat loss, resulting in a poor bond.

APPLICATION CONSIDERATIONS

- **Bead distribution**: Reflective bead application should be uniform across the entire line. Check for proper volume, distribution, and embedment. Remember that material temperature and thickness can also affect bead embedment. The material guns must be synchronized with the bead guns to ensure that the entire surface area of the material is properly reflectorized.

- **Mixing**: Material should be agitated frequently.

- **Application temperature**: Changing ambient temperatures can affect application. Beware, wind chill may cool the gun. Raising the thermoplastic temperature to compensate for this may result in overheating that may char the material.

- **Material adhesion**: Thermal bonding is essential. After the material has cooled, the bond can be checked for adherence. Refer to the government agency or manufacturer specifications for this procedure.

- **Maximum heating time**: Total heating time must not exceed the material manufacturer's recommendations.

- **Maximum holding time**: Do not hold thermoplastic above 400°F for more than six hours.

- **Maximum temperature**: At no time shall the thermoplastic exceed 475°F. Care must be taken not to exceed the flash point indicated in the government agency or manufacturer specifications.

- **Maximum reheats**: Reheat granular thermoplastic a maximum three times, block two times. Color change indicates the material is overheated and beginning to scorch: white thermoplastic turns beige or creamy; yellow may become pale, or develop a brownish or greenish tint.

- **Cleaning**: Schedule the melter for cleaning if charred or burned particles remain on the screen during transfer. Completely flush the system when changing from alkyd to hydrocarbon or vice versa.

Also, when changing from one color to another it is necessary to run several bags of the new color material through the entire system, and then discarded. This will ensure that the newly applied marking is the proper color.

- **Operating tip**: Completely drain kettle before overnight shutdown whenever possible (this will aid in expediting the loading process for the next production day). Keep the kettle closed to protect from moisture and other contaminants.

- **Precautions**: Guard against temperature loss during transfer.

- **Safety tip**: Keep a cooler of ice water on the long-line or hand-line machine during application. In case of accidental contact with hot thermoplastic material, use the ice water to cool the affected area immediately. Follow the instructions on the Materials Safety Data Sheet or call a physician. **DO NOT ATTEMPT TO PULL THE HOT THERMOPLASTIC MATERIAL FROM THE AFFECTED AREA.**

MATERIAL TESTING

Quality Control/Quality Assurance (QC/QA) or acceptance testing will be as described in each government agency's materials testing specifications.

Derived quantities are based on 4-inch, 5-inch, and 6-inch wide lines using hydrocarbon material and will vary with material specific gravity, application methods, and pavement surface texture. Alkyd has approximately 2.5 percent less yield due to the specific gravity of the material**.**

The following chart contains a typical testing measure to determine thermal bonding and thickness. For additional accuracy, contact the thermoplastic manufacturer for their thermoplastic yields.

APPROXIMATE THERMOPLASTIC YIELDS						
	FOR A 4-INCH LINE		**FOR A 5-INCH LINE**		**FOR A 6-INCH LINE**	
mils	lf/lb	lb/mile	lf/lb	lb/mile	Lf/lb	lb/mile
SPRAY APPLICATION – DENSE GRADED SUBSTRATE						
40	7.5	704	6.0	880	5.0	1,056
60	5.0	1,056	4.0	1,320	3.33	1,584
90	3.375	1,564	2.7	1,956	2.25	2,347
SCREED/EXTRUSION – DENSE GRADED SUBSTRATE						
60	4.5	1,173	3.6	1,467	3	1,760
90	3.125	1,690	2.5	2,112	2.08	2,534
125	2.25	2,347	1.8	2,933	1.5	3,520
SCREED/EXTRUSION – OPEN GRADED SUBSTRATE						
60	3.75	1,408	3.0	1,760	2.5	2,112
90	2.75	1,920	2.2	2,400	1.83	2,880
125	2.125	2,485	1.7	3,106	1.42	3,727

Figure 4.1
Approximate thermoplastic yields

INSPECTION AND QUALITY CONTROL

A vital component of quality assurance is inspection and quality control before, during, and after application. Regardless of the method of installation, there are some absolutes that must be followed.

These factors must be addressed to achieve good application:

- Type of material being used and thickness of application
- Temperature of material during application
- Ambient and surface conditions
- Reflective bead rate, pattern, and embedment

Type of Material

The proper type of material (alkyd or hydrocarbon) must be used based on which application is being performed. Even if all the other factors are correct, they can never overcome the use of the wrong type of material. For example, hydrocarbon may not be the best choice when applying a stop bar at an intersection that has heavy truck traffic. The oil and gasoline drippings can break down the resin causing premature failure.

Material Temperature

Temperature is very important in the proper mixing, melting, and bonding of thermoplastic. Temperature guidelines must be followed. Most manufacturers recommend 420°F as the ideal material temperature. If the material is too hot or has been heated too long, it will be scorched, which affects bonding, durability, and color. Material must also be agitated properly in the melting tank while being heated so that the intermixed reflective beads do not settle, thus altering the composition of the applied line. Also, thermoplastic that is too cold will cause application and durability problems. If thermoplastic is too cold, it will not melt into the roadway resulting in a poor bond. Thermoplastic that is too cold will also prevent the reflective beads from embedding deep enough, resulting in accelerated bead loss and lower retroreflectivity.

Ambient Conditions

An air temperature of at least 55°F and rising is typically required. Windy conditions may affect ambient temperature and cause material displacement during application.

Pavement Surface Considerations

Pavement surface temperature shall be at least 55°F and rising. The pavement surface must also be clean and dry. Keep in mind that surface conditions may change as the applicator goes from sunny to shady areas. When installed on porous surfaces, hot liquid thermoplastic fills voids, creating a good mechanical bond. Larger quantities of material may be required to yield the minimum thickness since the hot material sinks into the voids. To ensure a good bond, the material should not be applied too quickly to avoid entrapping air. All grease, oil, dust, dirt, and debris must be removed prior to applying thermoplastic. In addition, on concrete surfaces, curing compounds and laitance must be removed. Primer sealer must be used on all concrete surfaces.

Moisture

If hot thermoplastic is applied over a moist surface, pits will appear in the line resulting in delamination. Thermoplastic shall not be applied if moisture is present on the road surface.

The following test may be conducted to determine if moisture is present:

Tape an 18-inch square sheet of thin plastic to the road surface, being careful to seal all the edges. After 20 minutes, examine the bottom of the sheet and the road surface. If moisture is present, do not apply thermoplastic. Wait from 30 minutes to an hour and repeat the test until there is no moisture on the road surface or on the underside of the plastic.

Figure 4.2 is a troubleshooting guide for thermoplastic application problem.

THERMOPLASTIC APPLICATION TROUBLESHOOTING			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Applied line appears Rough on edges	• Material not cured	• Loss of durability • Out of standards	• Raise material temperature • Increase amount of material • Decrease atomizing air pressure (if spray application)
Applied line is wavy with irregular edges	• Material too hot • Application pressure too high • Extrusion gate too wide or material flowing past gate • Road surface uneven	• Poor reflectivity • Poor appearance • Poor durability	• Verify correct material for type of application • Adjust material temperature • Lower application pressure • Adjust application equipment/lower application rate
Line appears discolored, beige, or dingy (dull white)	• Material overheated or reheated too many times	• Does not meet color standard • Material is brittle - low durability	• Discard material
Line appears pitted	• Trapped moisture • Material not cured • Trapped air	• Poor surface bond - low durability	• Stop operation until road dries • Stop operation until primer cures • Slow application to fill voids in open graded pavement
Line appears lumpy	• Charred material • Unblended material	• Low durability	• If lumps appear burnt or dark in color, screen material to remove lumps. • If lumps appear grainy or unmixed, hold material at 420ºF until they dissolve
Line appears stretched or pulled	• Material applied too cold • Material applied too fast	• Poor surface bond - low durability	• Raise temperature • Lower speed of application

THERMOPLASTIC APPLICATION TROUBLESHOOTING-continued			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Line appears scarred or gapped	• Charred material • Dirt or debris on pavement surface	• Poor surface bond - low durability	• If lumps appear burnt or dark in color, screen material to remove lumps • Clean pavement surface
Line appears uneven at beginning or end	Applicator not adjusted properly	• Poor appearance	• Adjust applicator
Line exhibits dribbles between skips	• Applicator not adjusted properly	• Poor appearance	• Adjust applicator
Line marred by tire tracks	• Opened to traffic too soon • Insufficient reflective beads	• Poor reflectivity • Poor appearance	• Keep traffic off longer • Add more beads
REFLECTIVE BEAD PROBLEMS			
Line appears smooth, shiny, or glossy	• No reflective beads	• No initial reflectivity	• Adjust or reposition bead gun • Need more beads
Line appears smooth or dimpled	• Beads have sunk too low	• No initial reflectivity	• Lower material temperature • Reposition bead gun • Increase bead application rate
Line appears glazed	• Beads are not embedded properly	• Early loss of initial reflectivity	• Raise material temperature • Reposition bead gun
Line appears cratered	• Beads have popped out	• Low initial reflectivity	• Raise material temperature • Reposition bead gun

Figure 4.2
Liquid thermoplastic troubleshooting

CHAPTER 5 PREFORMED THERMOPLASTIC

OBJECTIVES

1) Preformed Thermoplastic
2) Components
3) Material Characteristics
4) Application Methods
5) Application Considerations
6) Inspection And Quality Control

PREFORMED THERMOPLASTIC

Preformed thermoplastic is a durable pavement marking system where thermoplastic symbols and legends are supplied in their final form and shape. Typically, the marking is supplied in large pieces, which are put together as a giant puzzle. Preformed thermoplastic pavement marking material combines the convenience of preformed markings with the performance qualities of hot applied thermoplastic. This heavy-duty intersection grade pavement marking material is ideal for high traffic areas where maximum wear and tear is present. Various brands are applied differently, so it is important to be familiar with the installation instructions for the type you are using. Always follow manufacturer instructions.

Type of Materials

There are two basic types of preformed thermoplastic markings:

1) Don’t require preheating the road surface to a given temperature
2) Require preheating the road surface to a certain temperature

COMPONENTS

Preformed thermoplastic markings are composed of pigments, reflective glass beads, fillers, binders and additives.

Pigments

Pigments are primarily used to impart color and to provide some chemical property, such as UV stability. Titanium dioxide is typically added to provide a white color. Lead chromate or organic pigment is typically added to provide a yellow color. Because of environmental and health concerns, the use of lead chromate compounds in pavement marking material is being eliminated.

Reflective Glass Beads

Preformed thermoplastic is produced at the factory with a certain percentage of beads intermixed within the melted material. Additional beads are also added to the surface of the material when it is applied.

Fillers

Fillers are typically a pigment and also provide bulk. Once the necessary color has been obtained, fillers such as a mixture of calcium carbonate, sand, and other inert materials are used to provide the volume of filler to give the necessary durability.

Binders (Resins)

Binders are thermoplastic; they melt when heat is applied. The binder holds the pigments, reflective beads, and fillers together. Heat is used to form the initial shape. The material does not change chemically on heating and application.

Additives

Additives such as plasticizers are added to control flow characteristics. Because the plasticizer can burn away, overheating and excessive reheating of preformed thermoplastic can affect the durability and overall quality of the marking.

Solvents

Preformed thermoplastic pavement markings contain no solvents. It is the heating process that transforms the thermoplastic material from a solid into a liquid.

MATERIAL CHARACTERISTICS

Other factors that should be considered when using preformed thermoplastics are packaging, shelf life and primers/sealers.

Packaging

Linear preformed thermoplastic is packaged in 3 to 4 foot long strips in sturdy cardboard boxes. Symbols are manufactured in pieces so they may be packaged and shipped easily.

Shelf Life

Preformed thermoplastic has a shelf life of one year when stored inside at a temperature between 35ºF and 95ºF. Due to the heavy weight of the thermoplastic, no more than 25 packs shall be stacked on top of one another.

Primers/Sealers

Primers/Sealers are used as a "bridge" between preformed thermoplastic and the surface where preformed thermoplastic will not readily adhere such as worn old HMA. Essentially, the primer bonds to the surface, and the thermoplastic bonds to the primer. In order to prevent moisture from entering under the marking on PCC, it is important to seal the surface with a primer/sealer before the marking is installed. This will help prevent failures during freeze/thaw periods. Follow manufacturer recommended installation instructions to ensure that the correct type of primer/sealer is used.

APPLICATION METHODS

Preformed thermoplastic can be applied with a propane-fueled heat torch. When you arrive at the work location, review the temperature conditions, weather conditions, and pavement conditions to make sure that the preformed thermoplastic can be successfully applied based on manufacturer recommendations. If the situation does not comply with the manufacturer's recommendations, it is recommended that you wait until conditions improve before installing the preformed thermoplastic.

Heat Torch

This method of application ensures that proper heat is applied to the preformed thermoplastic for a good bond to the road surface.

The flame of the propane fueled heat torch should be moved in a fan shaped pattern to ensure even heating of the material. To obtain the best results, the torch should be moved in a slow even motion approximately 4 to 12 inches over the material. It is helpful to keep the wind at your back so the heat will be carried across the marking.

Application on HMA

1) Thoroughly clean the application area. All loose particles (sand, dust, and other debris) must be removed. Utilize a power blower or compressed air if possible. Otherwise, sweep the entire area completely.

Figure 5.1
Cleaning pavement prior to application

2) Ensure that no moisture is present prior to positioning the preformed thermoplastic material on the pavement surface. A heat torch may be used to remove moisture.

3) If required, preheat the surface to the temperature recommended by the manufacturer. Not all types of preformed thermoplastic require preheating.

4) Position the preformed thermoplastic on the pavement surface. Position all connecting parts of the marking on the road with the exposed beaded side up. Make sure the marking is properly placed and that there are no gaps between the segments of legends and symbols.

Figure 5.2
Placement of material

5) Begin heating the material by moving the torch slowly and steadily over the material. Move the heat torch in a sweeping motion, approximately 2 feet wide over the marking at a height of 4 to 12 inches so that heat is evenly distributed across the marking, slowly melting the material. The preformed thermoplastic material must be heated throughout the process to achieve a bond with the pavement.

Figure 5.3
Arrow symbol being applied by heat torch.

6) As you heat the preformed thermoplastic, monitor the visual signs or temperature requirements. It is important not to "overheat" the material otherwise the top coating of beads will sink into the preformed thermoplastic and be less retroreflective initially.

7) Inspect the freshly applied preformed thermoplastic marking to ensure that complete bonding has occurred over the entire area. After the preformed thermoplastic has cooled to near ambient temperature, try to lift an edge or cut an area in the interior of the material with a chisel where it appears to have been heated the least. Try to lift a portion of the material; if the material can be lifted without evidence of asphalt on the underside, insufficient heat has been applied. Simply reapply heat until adequate bonding has occurred. This is called an "adhesion test."

Figure 5.4
Adhesion test being performed

8) When performing the adhesion test on material applied on PCC roads, you should see a thin layer of the material adhering to the road surface. After performing the adhesion test, remember to reheat the tested area.

9) Preformed thermoplastic will cool and set rapidly within a few minutes of application. If desired, setting time can be accelerated with a spray of cool water or hand casting of additional reflective glass beads on top of the marking.

Application on PCC or Old HMA

1) Follow steps 1, 2 and 3 as stated above for application on HMA. Worn, polished concrete should be ground or milled so the surface becomes rough.

2) Lay out the marking pattern using chalk or crayon as required for guidance.

3) Apply primer/sealer to areas outlined in chalk or crayon. Allow the primer/sealer to dry until it will not transfer to the finger when touched. The more porous the surface, the more sealer is required. **Caution: Do not accelerate the drying process by using an open flame. The sealer may be flammable at this stage.**

4) It is important to apply primer/sealer to the entire area where the preformed thermoplastic will be applied.

5) Continue with steps 4 through 9 as stated above for application on HMA.

APPLICATION CONSIDERATIONS

The pavement surface must be dry before applying preformed thermoplastic or primer/sealer. The pavement surface must also be free of dirt, dust, chemicals, and oily substances. Do not apply on top of any existing marking materials other than thermoplastic. However, first remove any loose thermoplastic and ensure that no moisture is present. If the old thermoplastic is oxidized (powdery surface), grind or heat it and scrape the top surface so fresh material is exposed. A primer/sealer may be required on PCC or old HMA. Make sure to follow manufacturer instructions.

Most preformed thermoplastic materials may be applied at air temperatures down to 35ºF. However, surface temperature is critical and must conform to manufacturer recommendations.

Protective clothing shall be worn during the installation of preformed thermoplastic pavement marking materials. The protective clothing shall consist of leather boots or work shoes, and long pants (note: synthetic fabrics should be avoided). General safety rules should be followed when using propane.

INSPECTION AND QUALITY CONTROL

A vital component of quality assurance is inspection and quality control before, during, and after application. Regardless of the method of installation, there are some absolutes that must be followed.

The following factors must be addressed in order to achieve good application:

- Sufficient heating of the material during application
- Ambient and surface conditions
- Reflective bead embedment

Never leave the job sites without performing the adhesion test (refer to Application on HMA Step 7, under Application Methods) to test the bond between the HMA and the material. Any deviation from manufacturer recommendations may result in application failures and shall be properly documented if unavoidable.

Figure 5.5 is a troubleshooting guide for preformed thermoplastic application problems.

PREFORMED THERMOPLASTIC APPLICATION TROUBLESHOOTING

PROBLEM	CAUSE	EFFECT	REMEDY
Bonding / Adhesion	• Surface is not clean	• Poor surface bond - low durability	• Clean with blower to remove surface debris
Bonding / Adhesion	• Moisture in road surface	• Poor surface bond - low durability	• Heat road to remove moisture
Bonding / Adhesion	• Non-conforming existing marking. (i.e. tape, paint, etc.)	• Poor surface bond - low durability	• Remove or install before of behind old marking
Bonding / Adhesion	• Deteriorating road surface	• Poor surface bond - low durability	• Resurface
Bonding / Adhesion	• Too little heating	• Poor surface bond - low durability	• Visual signs/ temperature should be observed
Bonding / Adhesion	• Deicing chemicals on road surface	• Poor surface bond - low durability	• Power wash area or wait till after rain to install

PREFORMED THERMOPLASTIC APPLICATION TROUBLESHOOTING-continued			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Bonding / Adhesion	• Dated Material	• Poor surface bond - low durability	• Rotate stock / 1 year shelf life
Bonding / Adhesion	• Curing agents on Portland Concrete Cement	• Poor surface bond - low durability	• Blast or power wash
Bonding / Adhesion	• Worn polished aggregates on road surface	• Poor surface bond - low durability	• Grind and blow clean
Bonding / Adhesion	• Lack of sealer	• Poor surface bond - low durability	• Use sealer
Low or No Retroreflectivity	• Too little or too much heat	• Glass beads not embedded enough or sunken into material	• Look for visual signs when heating
Low or No Retroreflectivity	• No surface beads/ poor hand casting	• Glass beads too few and unevenly distributed	• Use shaker to apply beads evenly
Low skid resistance	• Too much heat	• Glass beads sunken into material	• Look for visual signs
Low skid resistance	• No surface beads/ poor hand casting	• No beads to assist with skid resistance	• Use shaker to apply beads evenly
Smearing and discoloration	• Opened to traffic before marking has cooler down	• Reduced visibility	• Use reflective glass beads or water to cool material down or wait until cool
Discoloration of newly installed marking	• Tracking from new HMA • Oil dripping or other chemical spills	• Reduced visibility	• Use additional reflective beads to protect the new marking
Gaps between individual pieces not melted together	• Too little heat • Shelf life exceeded • Individual pieces not touching before heating	• Poor adhesion • Poor appearance	• Heat more • Rotate stock • Make sure pieces are touching before heating

Figure 5.5
Preformed thermoplastic troubleshooting

CHAPTER 6 EPOXY RESINS

OBJECTIVES

1) Epoxy Resin
2) Components
3) Characteristics of Epoxy
4) Method of Application

EPOXY RESIN

Epoxy resin is a durable, two-component pavement marking material consisting of a pigmented resin base and a hardener. Before installation, both components are mixed at a ratio of 2 parts resin: 1 part hardener, and applied by a specialized epoxy application truck. These criteria are based on the manufacturer's specifications. This material is sprayed and combined with drop-on reflective beads to provide nighttime retroreflectivity.

COMPONENTS

Pigments

Epoxy resin pavement markings use pigments, similar to all other pavement marking materials. Pigments are ground and dispersed into the resin side of the system.

Mixture

The epoxy resin is mixed with the hardener creating a binder system that is sprayed to form a durable pavement marking. To realize all the advantages of an epoxy system, it is critical that the components are properly mixed. Each component is stored in separate tanks on the epoxy application truck and heated to temperatures in accordance with manufacturer recommendations. Proportioning pumps draw the material at a 2:1 ratio. The material is then mixed by a static mixing tube and sprayed onto the road surface at approximately 1,200 psi.

Reflective Beads

Beads are uniformly applied across the entire width of the marking by a bead gun located immediately behind the epoxy spray gun. A double drop method is typically used for the application of the beads. Large and small beads are typically applied at a rate of 11 to 13 lbs/gal for each bead size for a total of 25 lbs/gal.

CHARACTERISTICS OF EPOXY

Epoxy striping material is classified as 100 percent solids, meaning the evaporation of solvents or water is not used to cure the material. Thus, without this evaporation process, a typical application rate of 20 mils wet yields 20 mils of dry material. Epoxy striping material is cured via a thermoset chemical reaction.

Advantages

- Good wet-night visibility
- Can be applied at lower temperature
- Makes a mechanical bond with the road surface
- Good bead retention
- Low profile resists snowplow damage
- Good life cycle costs
- Epoxy does not contribute volatile organic compounds

Disadvantages

- Slow cure (no-track time)
- Mix proportions are critical

METHOD OF APPLICATION

The mixed epoxy material is heated and sprayed onto the road surface. The equipment performing this operation is a specially designed epoxy truck that cannot be used to apply any other liquid binder material. Because of the composition of the material, environmental temperatures will increase or decrease the no-track times.

Shelf Life

Epoxy material has a shelf life of one year. The manufacture date should be stated in the shipping documents.

How to Mix the Material

The mix ratio for epoxy resin material is typically 2:1 (2 parts resin to 1 part hardener). It is very important that components are mixed thoroughly and at the correct ratio prior to being sprayed on the road surface. The mixing operation is a function of the epoxy installation truck. It shall be performed in accordance with manufacturer's recommendations.

Temperature

Epoxy shall not be applied unless the surface and ambient temperatures are a minimum of 35°F and rising. Remember that no-track times increase as the temperature decreases and vice versa. Always check temperature minimums (air and surface) for each agency when applying epoxy.

<u>Pavement Surface Considerations</u>

The road surface shall be free of curing compounds, laitance, oil, grease, salt, dust, or other debris. Epoxy materials shall not be applied if moisture is present on the road surface. Epoxy material can be applied behind the HMA paving operation as long as the mat has cooled enough to support the weight of the epoxy application truck. Epoxy materials can be applied over other epoxy materials. However, this shall only be done one time. Beyond that, removing the old material is required.

Figure 6.1 is an epoxy application troubleshooting guide.

EPOXY APPLICATION TROUBLESHOOTING			
SPRAY APPLICATION			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Heavy centers	• Inadequate fluid delivery	• Tracking • Erratic wear patterns • "Railroad Tracks" initially	• Increase fluid pressure • Decrease tip size
Light centers	• Inadequate fluid delivery	• Tracking from the edges • Erratic wear patterns • "Railroad tracking" with time	• Increase tip size • Replace tip
Surging pattern	• Pulsating fluid delivery	• Does not conform to standards • Erratic wear patterns	• Reduce demand • Remove restrictions in supply system • Check supply hose for leaks
"Lop sided" millage	• Worn tip sides • Clogged tip	• Erratic wear patterns	• Replace tips • Clean tips
Line too wide	• Gun too high • Too wide a fan angle on tip	• Does not meet standards	• Lower gun • Adjust tip size if necessary

EPOXY APPLICATION TROUBLESHOOTING – continued			
SPRAY APPLICATION			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Line too narrow	• Gun too low • Too narrow a fan angle on tip	• Does not meet standards	• Raise gun • Adjust tip size if necessary
Applied line too thin	• Inadequate tip hole • Traveling too fast for tip size • Change in delivery pressure	• Poor durability • Does not meet standards	• Change tip size • Decrease speed of application • Verify pressure settings
Applied line too thick	• Too large a tip size • Traveling too slow for tip size • Change in delivery pressure	• Too long a cure time • May cause shape problems • Poor retro-reflectivity due to buried beads	• Change tip size • Increase speed of application • Verify pressure settings
Too much hardener	• Displacement pumps not properly synchronized	• Dark or black lines • Takes too long to cure	• Adjust pumps
Too little hardener	• Displacement pumps not properly synchronized	• Poor durability	• Adjust pumps

Figure 6.1
Epoxy troubleshooting chart

CHAPTER 7 POLYESTER RESIN

OBJECTIVES

1) Polyester Resin
2) Components
3) Characteristics of Polyester Resin
4) Methods of Application

POLYESTER RESIN

Polyester resin material is a three-component material. However, the manufacturer mixes the two reactive parts. At the time of application, a catalyst is added to start the reaction. Then the material is sprayed onto the roadway. Reflective beads are added using a separate gun located directly behind the paint gun.

COMPONENTS

Pigments

The material is composed of pigments that are very similar to those used in other pavement markings. The pigments are used to impart color, hiding and other desirable properties, like all other markings. However, these pigments are pre-ground prior to being blended into the resin.

Resins

The marking has polyester resin that is mixed with a reactive solvent, a styrene compound. Normally, solvents are expected to evaporate and not participate in the setting up process. In addition to acting as a solvent, the styrene participates in the polymerization process. In order for this material to begin to react, a catalyst must be added to initiate the reaction.

Additives

Driers are added to assist in the curing process.

Reflective Beads

Beads are uniformly applied across the entire width of the marking by either a gravity or pressurized bead applicator located immediately behind the polyester spray gun. Beads are generally applied at a rate of 8 lb/gal.

CHARACTERISTICS OF POLYESTER RESIN

The material has the potential to be 100 percent solid. This depends on how fast the reaction takes place. The styrene is volatile prior to the reaction. Heat is not typically added to the system except when cure time is expected to be long, such as on cool spring or fall days. The catalyst is added to drive the reaction. Usually, the catalyst is methyl ethyl ketone (MEK) or benzoyl peroxide. The polyester resin and the styrene solvent react together to crosslink, or polymerize, to form a film. The polyester resin system will not cure properly if the appropriate quantity of catalyst is not added.

Advantages

- Catalyst proportioning is not critical
- Essentially two components in one container
- Long lasting and durable
- Does not discolor badly
- Relatively inexpensive
- Works well on concrete

Disadvantages

- Peroxide catalyst is a very reactive oxidizer
- Requires placarding as a hazardous material
- Requires commercial drivers license
- Flush solvent is flammable and a hazardous waste
- Moisture in surface a major factor and detriment
- HMA paving oils are a detriment
- Set up time depends on type of resin (usually 3-20 minutes)
- Difficult to determine whether mixed properly

METHODS OF APPLICATION

The catalyst can be added by either external or internal mixing. External mixing requires the use of two guns; one sprays the catalyst into and on the freshly applied liquid immediately prior to reflective bead application. This is the preferred method when an airless gun is used.

With a conventional system, it is possible to have a set up where the catalyst is injected into a mixing chamber within the gun, by which the catalyst is added to the material stream. Atomizing the air mixes the material just prior to it being sprayed onto the roadway.

Ambient Conditions

The lower the air and road surface temperature, the longer it will take for the material to react and set up. There are two types of material: a slow dry that takes about 10 minutes at 70°F and a fast dry that takes about 3 minutes at 70°F. The minimum road and air temperature to apply polyester pavement marking is 50°F and rising.

Temperature

The material is not dependent upon heat to make it set up. However, the application of minimal heat (130°F) is helpful in the spring and fall.

Pavement Surface Considerations

Polyester cannot be applied to new HMA until the road surface oils have been removed. Concrete must have curing compounds, latency, dust, dirt, and other debris removed prior to application.

Figure 7.1 is a polyester application troubleshooting table using the conventional application method. Figure 7.2 is a polyester application troubleshooting table using the airless application method.

POLYESTER APPLICATION TROUBLESHOOTING			
CONVENTIONAL APPLICATION			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Thick millage (middle of line)	• Material tank pressure too high • Control screw open too wide • Atomizing air pressure off or too low • Pump pressure too high	• Tracking or uneven wear or buried beads	• Reduce material pressure • Close control screw • Increase atomizing air pressure if material usage is OK • Lower pump pressure
Insufficient millage (center of line)	• Atomizing air pressure too high • Tank pressure too low • Pump pressure too low	• Poor quality line or short life	• Decrease atomizing air pressure • Increase tank pressure • Increase pump pressure
Wide paint line	• Paint gun height excessive	• Line does not meet standards	• Lower gun • Use or adjust shrouds if edges "fuzzy or light
Narrow paint line	• Paint gun too low • Spray nozzle slot not 90 degree angle to paint line • Paint clogging spray nozzle	• Line does not meet standards	• Raise paint gun • Adjust spray nozzle • Clean spray nozzle
Paint line "ratty" (uneven or spotty)	• Atomizing air pressure too low • Material pressure too low • Old paint (viscosity too high) • Worn fan cap • Insufficient heat	• Poor appearance	• Increase atomizing air pressure • Increase material pressure • Rotate stocks • Replace fan cap • Apply small amount of heat during application (no more than 120 °F)

POLYESTER APPLICATION TROUBLESHOOTING –continued			
CONVENTIONAL APPLICATION			
PROBLEM	**CAUSE**	**EFFORT**	**REMEDY**
Thick wet millage	• Control screw open too wide • Material pressure too high • Atomizing air pressure too high • Truck traveling too slow	• Tracking and/or buried beads	• Close control screw • Reduce tank pressure • Adjust atomizing air pressure • Increase truck speed
"Railroad tracking"	• Atomizing air pressure too high • Bead pressure too high • Catalyst not spraying evenly	• Tracking only on the edges • Tracking in sections of the line	• Adjust atomizing air pressure • Adjust bead pressure • Clean catalyst gun tip
Heavy millage on one side	• Clogged tip • Clogged shroud	• Tracking • Buried beads	• Clean tip • Clean shroud
Too long a cure time	• Not enough catalyst • Catalyst not spraying evenly (in a gun system)	• Tracking • Loss of durability	• Adjust amount of catalyst • Adjust angle of catalyst gun if applied separately
Line darkens noticeably overnight	• Too much catalyst • Darkening due to dirt pickup	• Poor appearance • Loss of durability	• Reduce amount of catalyst • Check line for after tack

Figure 7.1

Polyester application troubleshooting for conventional application

POLYESTER APPLICATION TROUBLESHOOTING			
AIRLESS APPLICATION			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Heavy centers	• Inadequate fluid delivery	• Tracking • Erratic wear patterns • "Railroad tracks" initially	• Increase fluid pressure • Decrease tip size
Light centers	• Inadequate fluid delivery	• Tracking from the edges • Erratic wear patterns • "Railroad tracking" with time	• Increase tip size • Replace tip
Surging pattern	• Pulsating fluid delivery	• Does not conform to standards • Erratic wear patterns	• Reduce demand • Remove restrictions in supply system • Check supply hose for leaks
"Lop sided" millage	• Worn tip sides • Clogged tip	• Erratic wear patterns	• Replace tips • Clean tips • Lower gun
Line too wide	• Gun too high • Too wide a fan angle on tip	• Does not meet standards	• Lower gun • Adjust tip size if necessary
Line too narrow	• Gun too low • Too narrow a fan angle on tip	• Does not meet standards	• Raise gun • Adjust tip size if necessary
Applied line too thin	• Inadequate tip hole • Traveling too fast for tip size • Change in delivery pressure	• Poor durability • Does not meet standards	• Change tip size • Decrease speed of application • Verify pressure settings
Applied line too thick	• Too large a tip size • Traveling too slow for tip size • Change in delivery pressure	• Too long a cure time • May cause shape problems • Poor retro-reflectivity due to buried beads	• Change tip size • Increase speed of application • Verify pressure settings

Figure 7.2

Polyester application troubleshooting for airless application

CHAPTER 8 PREFORMED TAPE

OBJECTIVES

1) Preformed Tapes
2) Components
3) Types of Preformed Tapes
4) Methods of Application
5) Pavement Surface Considerations

PREFORMED TAPES

Preformed tapes come in rolls. The tape consists of pigments, resins, and reflective materials (glass beads or reflective elements) and comes ready to use with or without adhesives. Additional adhesive (primer) can be applied to the pavement to enhance the bond. This material can be used for lane lines, legends, symbols, and transverse markings.

COMPONENTS

Tapes are similar to other markings: pigments are used to produce color, and suitable resins are used to provide the necessary wear characteristics.

Resins

Pre-reacted resins hold the beads and pigments in place. For this reason, the tape is ready for installation upon delivery. Additionally, there may be an adhesive backing on the bottom side of the resin for adhesion to the roadway surface.

Reflective Materials

The manufacturer has already added reflective materials to the resin. Additional reflective materials are not added in the field.

Primers/Glues

Tapes, depending upon the type, may use primer and/or adhesives in addition to those already applied by the manufacturer. These various compounds are used to promote adhesion to the roadway surface.

Generally, tape that has been properly stored (sheltered at room temperature) will be usable for a period of one year. In addition to the normal requirements for accepting materials on the project, the manufacturer's expiration date must also be clearly shown. Certification letters for the tape, and for all related sealers and primers must be provided.

TYPES OF PREFORMED TAPES

Tapes fall into one of two categories: permanent and removable.

Permanent Tapes

Permanent pavement marking tapes are either flat or patterned. These tapes may require the use of a primer/sealer (unless otherwise recommended by the manufacturer). The cost of the sealer is usually included in the price of the tape. When applied properly, this material resists movement under traffic. A primer/sealer shall be applied to the roadway prior to the application of this material. Permanent tapes are generally used for longitudinal edge lines, skip lines, stop lines, crosswalks, legends, and symbols.

Patterned tape is textured, and is sometimes referred to as "profile tape." Patterned tape used for longitudinal edge lines or skip lines on HMA is usually in-laid.

Removable Tapes

Removable tapes can be removed (pulled from the pavement surface) without using heat, solvents, or mechanical eradication. Generally, these tapes should be removed within 6 months of installation and should not leave any permanent residue on the road surface. The use of primers or additional glue may or may not be required. Although these tapes are similar in appearance to permanent tape, they may have an additional fiber mesh bonded in the resin. This mesh provides the necessary tensile strength allowing the tape to be pulled up from the roadway without breaking or tearing.

Blackout or black tape is another type of removable tape that is used to temporarily cover existing marking on an HMA road. Black tape, however, does not contain any reflective material. For example, if a permanent lane needs to be temporarily moved during construction and then reestablished at a later time, the black tape could be applied over the existing lines to hide them and new lines applied with another removable tape. When construction is complete, the original lanes can be reestablished by removing the black tape and the other temporary tapes. Black tape shall not be used on PCC roads.

METHODS OF APPLICATION

Flat and patterned tapes are normally installed by using a roller applicator. This is a walk-behind push cart that holds and applies one or two rolls of tape. The applied tape is then pressed onto the road surface using a walk-behind tamper cart. Weights are stacked on this cart to provide the necessary force to press the tape to the road. The tape manufacturers specify the required weight needed for each type of tape. This roller applicator and tamper procedure helps ensure that the tape is applied straight, especially in long line applications. If the manufacturer requires additional primers or glues, they can either be rolled or sprayed onto the tape and/or road surface.

When patterned tape is in-laid, no primer is used. It is in-laid with the last pass of the paving roller; the temperature of HMA is critical.

PAVEMENT SURFACE CONSIDERATIONS

The minimum application temperature is determined by manufacturer recommendations. Prior to the application of the tape, the surface must be free of contaminants. Contaminants may include dust, dirt, or moisture. If tape is applied to a surface containing dust, dirt, or moisture, poor adhesion will result. This situation should be avoided.

Refer to Figure 8.1.

PREFORMED TAPE APPLICATION TROUBLESHOOTING			
PROBLEM	**CAUSE**	**EFFECT**	**REMEDY**
Material rolls up or shifts	• Not bonded prior to traffic • Tape crossing traffic • No primer adhesive	• Loss of effectiveness	• Replace material with proper tamping, adhesive and primer.
Poor Material adherence	• Moisture in pavement • Dirty surface • No primer • Expired shelf life	• Errant delineation • Loss of Material • No delineation	• Replace material applying properly

Figure 8.1
Preformed tape troubleshooting chart

*Note: Since the material is preformed, the only actions that are necessary are being sure that the material is the correct material specified, is placed properly, and is applied properly. FOLLOW MANUFACTURER RECOMMENDATIONS.

CHAPTER 9 PAVEMENT MARKERS

OBJECTIVES

1) Pavement Markers
2) Types of Pavement Markers

PAVEMENT MARKERS

Pavement markers are pre-manufactured, reflectorized devices that provide positive in-roadway delineation at night, especially during inclement weather and in areas where roadway alignment variations dictate guidance that cannot be achieved by pavement markings and roadside delineation alone. The Manual on Uniform Traffic Control Devices (MUTCD) allows the use of pavement markers as a supplement to traditional longitudinal markings. Pavement markers cannot be used as a replacement for standard linestriping.

TYPES OF PAVEMENT MARKERS

Pavement markers are composed of a base material that is designed to resist impacts from traffic and to provide an adherent surface securing the marker to the roadway. Some agencies use a series of hard, non-reflectorized raised markers to form a line where overhead lighting is available. Other agencies require that all pavement markers be reflectorized. The retroreflective surface can either be reflective sheeting or a prismatic reflector. The outer cover of the prismatic area can be either plastic or glass.

The most common types of pavement markers are raised temporary, recessed snow plowable, and raised snow plowable.

Raised Temporary Markers

Raised temporary markers are normally used with construction zone markings. They are commonly referred to as "temporary markers" or “RPMs”. Specifications often require the use of temporary pavement markers in transition areas of work zones that will encroach upon the traveled roadway for a period of more than two days, and in other areas as required by the engineer.

These markers are glued to the roadway with a bitumen or epoxy adhesive. Most markers of this type consist of a plastic body with a reflective surface.

These pavement markers shall be replaced when they become damaged or have been removed by traffic. These markers will be inspected on a routine basis and replaced as necessary.

Another general type of temporary raised marker is the "peel and stick type". These markers generally have a paper backing that is removed to expose a butyl/adhesive pad. The marker is then applied to the roadway and firmly pressed in place. Figure 9.1 shows a variety of raised temporary markers.

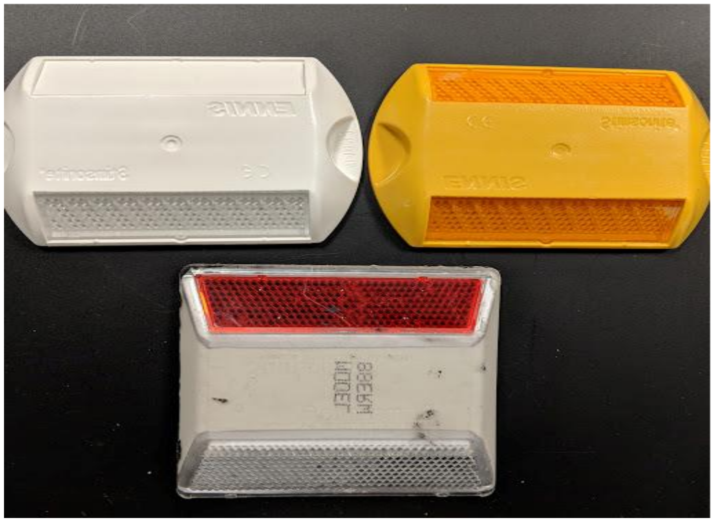

Figure 9.1
Raised temporary markers

<u>Recessed, Snow Plowable Marker System</u>

This marker system consists of a tapered slot that is cut into the roadway. A marker similar to the raised marker is affixed in the slot using epoxy. This design allows the snowplow blade to slide over the slot and not contact the marker because it is just below the roadway surface.

These markers can only be used effectively where there is sufficient traffic speed (35+ mph) to "whip" out any water and/or dirt that may collect on or in front of the marker lenses. This type of marker has a plastic body with a reflective surface. Figure 9.2 shows several recessed, snow plowable pavement

Figure 9.2
Recessed snow plowable markers

Raised, Snow Plowable Marker System

This marker system generally consists of a reflective marker glued in a protective steel or cast-iron casting. This casting is applied with epoxy into a groove that is cut in the pavement surface. The system is designed so that a snowplow blade will ride up and over the reflective marker, leaving it undamaged. The reflective marker can be replaced in the casting. Figures 9.3a and 9.3b show a raised snow plowable marker system.

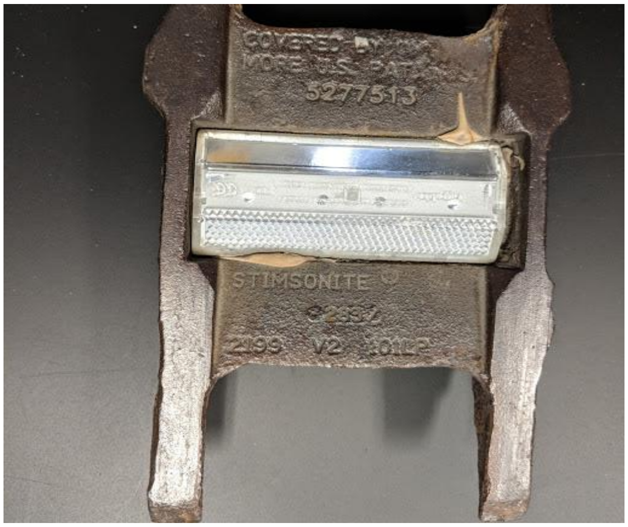

Figure 9.3a
Raised, snow plowable marker system

Figure 9.3b
Raised, snow plowable marker system shown in-place

SECTION III

INSTALLATION OF PAVEMENT MARKINGS

CHAPTER 10 INSTALLATION AND QUALITY CONTROL

OBJECTIVES

1) Pre-Installation Considerations
2) Quality and Workmanship

PRE-INSTALLATION CONSIDERATIONS

To ensure quality, there are some important steps that must be taken before the pavement marking material is installed.

The three primary objectives of project management that must be met before any markings are applied are material verification, review of pavement marking layout details, and pre-construction discussion.

Material Verification

To verify that the correct materials are supplied and used on the job, the contract material specifications must first be reviewed. Material test results and/or product identification must then be compared against specifications to ensure that they are correct. Project inspectors and contractors must be familiar with the application requirements for all the specified material. Materials may be specified or required in several areas of the contract. Specifications may be modified or changed through addendums or special provisions. All additions to the published specifications, as well as the effective date of the specifications and standards, are listed in the job proposal.

Review of Pavement Marking Layout Details

The layout of all markings shall be reviewed in detail. Additionally, all drawings and measurements shall be reviewed for accuracy. The layout is either included in the plans or referenced in the standard plans and drawings.

Pre-construction Discussion

Agencies typically require that only materials approved by the engineer shall be used on the project. At the pre-construction meeting, the project engineer, inspector and contractor will review and discuss the acceptance procedures and specifications in general. The type of materials, methods of application, and other installation considerations should be discussed.

QUALITY AND WORKMANSHIP

The successful installation of pavement markings depends upon a logical sequence of events that involves planning, installation, and acceptance. These steps are necessary to ensure that:

- All materials have been tested in accordance with the specifications. Quality Control/Quality Assurance (QC/QA) or acceptance testing shall be performed as set forth in each agency's material testing specifications.

- Proper markings are installed at the intended locations.

- The completed installation meets the criteria established in the specifications for quality and workmanship.

- The finished product is aesthetically pleasing and provides clear direction to motorists.

The sequence of events to be followed is divided into pre-application, application, and post-application time frames.

Pre-Installation: Contractor's Responsibility and the Agency's Responsibility

- The plans, contract, specifications, and MUTCD shall be reviewed to determine the location and type of pavement markings to be installed. Also, review the plans and the contract to ensure that the type of material specified conforms to the contract documents.

- Project personnel and quality control (QC) technicians shall ensure that an approved source of materials, including certified delivery tickets, has been furnished for the types of materials used.

- A copy of the manufacturer's installation recommendations must be obtained and supplied by the contractor for the type of materials used. Specific recommendations shall be followed in conjunction with the specifications.

- A copy of the Material Safety Data Sheet (MSDS) must be obtained, as required by Occupational Safety and Health Administration (OSHA) for each type of material to be used or work is not to proceed.

- The contractor must obtain and complete all required documents from the governing agency.

- The project inspector and QC technician shall ensure that weather and surface conditions comply with the specification requirements prior to allowing pavement marking operations to begin.

- The project personnel and QC technician shall ensure that the pavement marking field layout (pre-marking) conforms to plans and MUTCD requirements.

- The project personnel and QC technician shall ensure, through random inspection, that materials are applied in accordance with contract documents.

- Striping equipment shall be checked for proper calibration and obvious mechanical deficiencies. The contractor is required to demonstrate that all equipment is capable of performing the intended work prior to beginning actual application.

Installation

The contractor shall measure the application thickness, color, and the bead application rate at the beginning of each workday and a minimum of every three hours thereafter, for paint, thermoplastic, and epoxy. State agency specifications designate required procedures. Once application of the pavement markings begins, the following items should be closely monitored:

- Traffic control must be constantly monitored to minimize disruption and to ensure compliance with the government agency's traffic control manual and the MUTCD. Material temperatures shall be randomly checked during application.

- In order to prevent tracking, the applied material must be completely cured prior to opening to traffic.

- The inspector will ensure that the contractor performs quality control testing in accordance with the government agency specifications.

- The temporary pavement markers should be installed according to the contract documents, specifications, and manufacturer recommendations.

- The contractor’s quality control technician must constantly monitor the quality and workmanship of the material being applied. Line width, length, thickness, and color shall be checked frequently to ensure compliance with the contract documents, and a written report (quality control report) shall be submitted to the agency’s inspector.

- Unacceptable work must be identified, reported to the contractor, and corrected prior to payment.

- Pay quantities for materials being applied shall be measured and documented after each operation.

- Payment for completed work shall be dependent on the quality assurance inspection and contract requirements.

CHAPTER 11 EQUIPMENT

OBJECTIVES

1) Basic Components
2) Pre-Stripe Inspection
3) Quality Control

BASIC COMPONENTS

Pavement marking equipment comes in many shapes and sizes. All equipment manufacturers have their own configuration of basic components for a given application. A long-line paint truck manufactured by one company may look considerably different from the paint truck of a different manufacturer.

Although a specific machine is built to apply a specific type of material, all pavement marking equipment, except preformed tape applicators, will generally fall into one of the following categories: long-liners and hand-liners.

Long-liners, as the name implies, are designed to produce long distance pavement markings. They are self-propelled and are equipped to carry relatively large quantities of material. Most are set up with more than one applicator or spray gun. Figure 11.1 shows a typical long liner. Hand-liners, which are much smaller than long-liners, are generally designed for operators to walk behind. They can only carry a limited quantity of material. The need for walk-behind applicators may be stated in the contract documents. Figure 11.2 illustrates a typical walk-behind applicator.

Figure 11.1
A typical long-liner

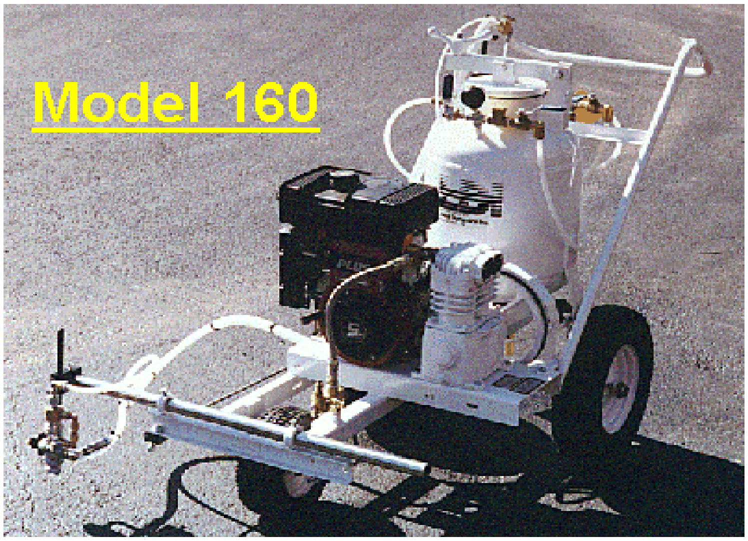

Figure 11.2
A typical walk-behind applicator

Long-liners vary somewhat from the specific systems they incorporate based on the type of pavement marking material they are designed to apply (paint, epoxy, thermoplastic, etc.). However, the following components can be found on all long-liners:

- Air compressor (airless applicators included)
- Material holding tank (with mechanical agitators)
- Reflective bead tank (pressurized)
- Cleaning system (cannot be in-line system)
- Material heating system (if necessary)
- Material applicators (spray guns, etc.)
- Reflective bead guns
- Control system (spray gun control, skip timer, etc.)
- Counter system (for measuring distance and/or material)
- Guidance aid (some means for the operator to line up with the road or with existing markings)

PRE-STRIPE INSPECTION

The following is the recommended procedure for the engineer prior to beginning work on the project:

- The engineer will become familiar with the equipment by walking around it with the operator. They should discuss how the machine is set up and how it operates. During this discussion, the engineer should learn the location of each component and be assured that everything is in working order. The preceding checklist may be used as a guide for this procedure.
- The contractor shall apply a sample marking for inspection. While this is taking place, the engineer will ensure that the contractor is taking quality control test samples for thickness and width of material, and reflective bead application rate (according to government agency specifications). The results of the quality control tests shall be reviewed and discussed with the contractor.
- Before proceeding with the work, the engineer will inspect the marking and test panels for quality, clean edges, even bead distribution, proper bead depth, required width, and general appearance. This is discussed in detail in the appropriate chapter in this manual.

If any problems or inconsistencies are discovered, DO NOT PROCEED WITH THE WORK!

QUALITY CONTROL

Clear communication and cooperation yields positive inspector/contractor interaction and helps ensure quality. This is essential regardless of the type of work. Discuss any problems with the contractor's certified quality control technician and stay informed of the adjustments the contractor makes to correct them. The following guidelines will ensure proper quality:

- Once the work is in progress, the engineer and contractor's quality control technician shall periodically stop, get out of the truck, and inspect the line.
- Continuous close attention to the appearance of the line is the best way to ensure quality work.
- Generally, inspection of the actual marking is the best tool for determining equipment problems.
- Proper width does not ensure even edges.
- Proper material thickness does not ensure adhesion.
- Proper bead application rate does not ensure either retention or proper embedment.
- To ensure quality, the pavement markings must be inspected closely.

Typically, the contractor's certified quality control technician is required to make the quality control checks according to the government agency's specifications. The purpose behind any quality control plan is to ensure quality. Whenever there are any doubts about the quality of the work, they MUST be investigated.

Deficiencies may or may not be due to equipment problems. When everything is working properly, pavement markings can be compared to an orchestra; all the components must work together. Material properties, weather conditions, and operator skill can all affect the quality of the final marking. Diagnosing the cause or combination of causes for a given problem can be very difficult. Engineers and inspectors who are knowledgeable about pavement marking equipment are better able to identify equipment problems.

As always, it is the responsibility of the contractor to solve the problem. However, this should never be misconstrued to lead the engineer away from helping to identify problems. In other words, although the engineer cannot tell the contractor how to fix a problem, knowledgeable engineers can and should be considered a valuable tool for the contractor, always keeping in mind that quality is the main goal.

CHAPTER 12 ERADICATION

OBJECTIVES

1) Definition/Purpose
2) Undesirable Effects
3) Methods of Eradication
4) Specifications
5) Inspection

DEFINITION / PURPOSE

Eradication describes the removal of existing pavement markings. Pavement markings are eradicated to change or modify the existing travel lanes and to prepare the road surface for new markings.

UNDESIRABLE EFFECTS

If pavement markings are not eradicated properly, several different markings may exist at the same time, as shown in Figure 12.1. Often, the scars left by some removal methods may appear like additional pavement markings (see Figure 12.2). This may create a hazardous condition for motorists.

Figure 12.1
Roadway with confusing multiple lines

Figure 12.2
Scars from removed marking

It was once common practice to cover the existing marking with either black paint or asphalt (Figure 12.3). Heavy traffic would often wear away this paint or asphalt and the unwanted marking would become visible again. From a safety perspective, this is not a practical solution <u>except</u> for extremely short durations (i.e. overnight).

Figure 12.3
Black paint wearing off of previous marking

METHODS OF ERADICATION

There is no method of eradication that is free from drawbacks. Whatever the method, it must effectively remove the marking to the specified degree, while at the same time doing the least damage to the pavement. Eradication methods must be submitted to the governing agency for approval prior to beginning the work.

Methods that have typically been used are:

- Blasting (hydro, sand or shot)
- Grinding

The effectiveness of the method is dependent on three things:

- The type and thickness of the marking being removed
- The type of pavement
- The skill of the operator

For example, thermoplastic markings cannot withstand abrasive blasting because the heat generated when the abrasives strike the marking melts the thermoplastic. Grinding is not acceptable on grooved or tined PCC because it will remove the texturing of the pavement surface. Most chemical strippers are hazardous materials with disposal problems. Heat can make HMA pavement slick. Depending on the amount of heat, safety problems may result. This is particularly true if yellow markings containing lead are removed. Hydro-jetting or hydro-blasting uses water and can cause slick pavements in the wintertime.

SPECIFICATIONS

Each government agency will specify how eradicated residue and dust is to be contained and disposed.

INSPECTION

The eradicated lines are to be inspected for:

- Thoroughness of eradication
- Damage to the pavement surface

SECTION IV

APPENDICES

APPENDIX A SPECIFICATIONS

The following contact numbers may be used to obtain pavement marking specifications for the respective state:

Maryland	**800-637-1290** Ask for Specification Team
New Jersey	**609-530-2001**
Pennsylvania	**717-787-3620**
Virginia	**804-786-1898**
West Virginia	**304-558-3063**

APPENDIX B METRIC CONVERSION INFORMATION

SI METRIC

SI Metric stands for "Le Systeme International d'Unites", which means "The International System of Units". The metric system is a decimal-based system, a system in which units are related to each other in factors of ten. Our money system is a decimal based system. A penny is one-hundredth of a dollar.

The following metric units will be used by pavement marking crews:

Meters (m) - A meter is approximately the length of an outstretched arm from the fingertips to the shoulder of the other arm.

Kilometers (km) - The metric prefix kilo means one thousand. A kilometer is one thousand meters.

Millimeter (mm) - The prefix milli means divided by a thousand. A millimeter is one thousandth of a meter.

Centimeter (cm) - The centimeter is the measurement of length that is one hundredth of a meter.

0.001 kilometer = 1 meter = 100 centimeters = 1000 millimeters

Kilogram (kg) - The metric unit for measuring mass.

Liter (L or l) - The metric unit for measuring fluid volume.

Degrees Celsius- The temperature scale in the Celsius system is determined as follows: The temperature at which water freezes is marked at 0 degrees Celsius. The temperature at which water boils is 100 degrees Celsius. The difference between these two points is divided into 100 equal parts. On a Fahrenheit scale water freezes at 32 degrees and boils at 212 degrees.

Micron – The prefix micro means divided by one million. A micron is one millionth of a meter.

Try estimating measures and dimensions directly in SI units. Even if your estimates are not correct, continue trying. With every estimate you will be a step closer to "thinking metric".

CONVERSION ENGLISH TO METRIC

Multiply	By Conversion Factor	To Obtain
Mils	0.0254	Millimeters
Inches	25.4	Millimeters
Inches	2.54	Centimeters
Feet	0.3048	Meters
Yards	0.9144	Meters
Miles	1.6093	Kilometers
Pounds	0.4536	Kilograms
Gallons	3.785	Liters
Square feet	0.0929	square meters
Inches	0.00003937	Microns

Degrees C = 5/9 (F - 32)

CONVERSION METRIC TO ENGLISH

Inch Micron

Multiply	By Conversion Factor	To Obtain
Millimeters	39.37	Mils
Millimeters	0.03937	Inches
Centimeters	0.3937	Inches
Meters	3.2808	Feet
Meters	1.0936	Yards
Kilometers	0.6214	Miles
Kilograms	2.2046	Pounds
Liters	0.264	Gallons
Square meters	10.76	square feet
Microns	25,400	Inches

Degrees F = (9/5 x C) + 32

Example Problem: How many meters are there in 2.50 yards?

2.50 x 0.9144 = 2.286 meters

PRACTICE PROBLEMS

1) If 50 gallons of yellow traffic paint are loaded on the truck, how many liters does this equal?

2) 950 linear feet of traffic tape was placed starting at station 1528+00, how many meters were placed?

3) Convert the following to metric:

   12 lbs. yellow thermoplastic

   120 yards tape

4) A contract calls for 25,250 linear feet of tape. How many meters is this?

5) Convert the following to English units:

   0.34 kilograms of reflective beads

   600 millimeters of stop line marking

6) The surface temperature at time of application of thermoplastic must be 10 degrees Celsius and rising. What is this in degrees Fahrenheit?

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