
2

Reflective Glass Beads

Learning Outcomes:

- ☑ Understand how glass beads perform.
- ☑ Ability to evaluate correct glass bead application for retroreflectivity.

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

How Glass Beads Work

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.

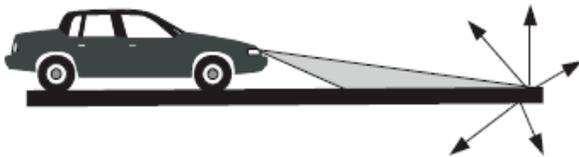


Figure 2.3

Roadway with unbeaded markings

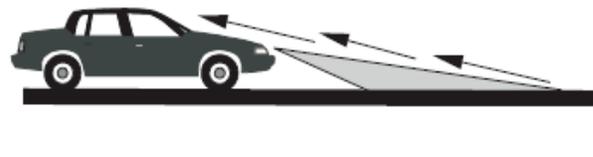


Figure 2.4

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.

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.

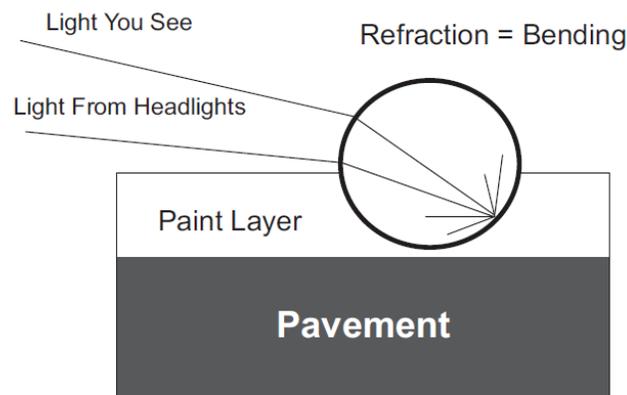


Figure 2.5

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

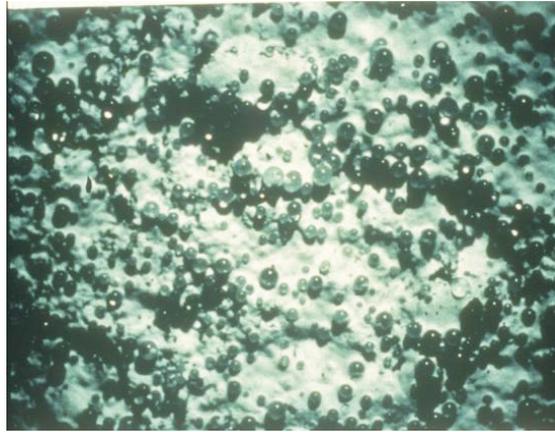


Figure 2.7a
Top view of reflective beads applied to a layer of paint that is too thin

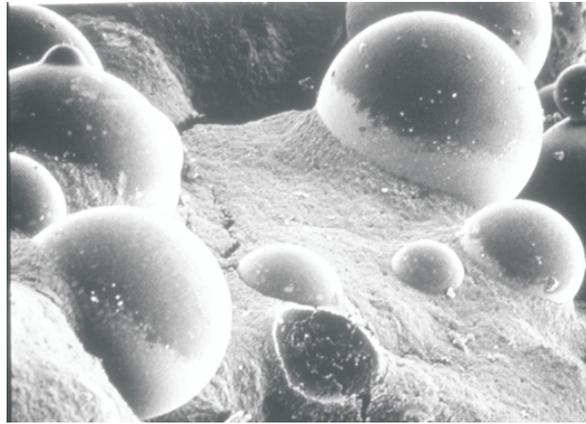


Figure 2.7b
Magnified view of reflective beads applied to a layer of paint that is too thin

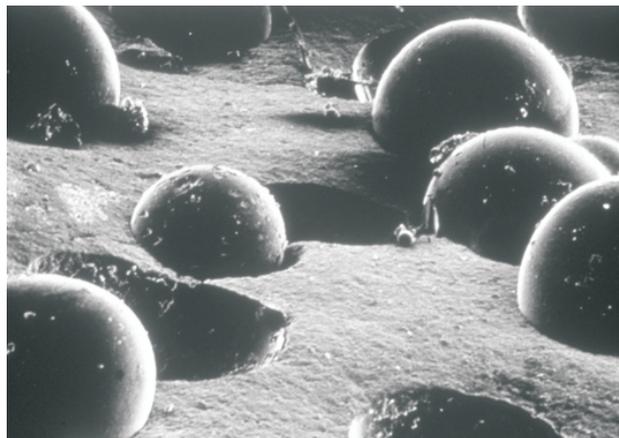


Figure 2.8
Magnified view of reflective beads at proper embedment depth

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.

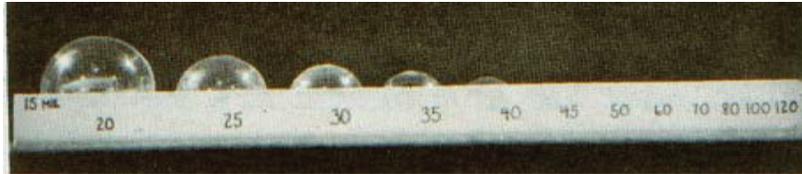


Figure 2.9
Beads in a 15 mil wet line



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.

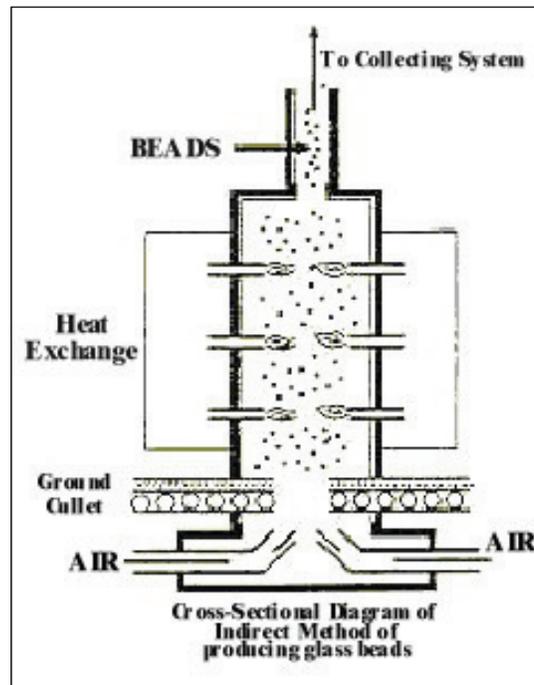


Figure 2.11
Indirect method for manufacturing glass beads

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.

Size or Gradation

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				Range For Larger Beads Depending On Binder			
	U.S Sieve	Microns	Inches		U.S Sieve	Microns	Inches
•	80	180	.0070	●	16	1180	.0469
●	50	300	.0117	●	14	1400	.0555
●	30	600	.0234	●	12	1700	.0661
●	20	850	.0334				

Figure 2.12
Relative bead size comparison

Roundness

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 (light bending phenomenon) 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 U.S. Sieve Sizes	MASS PERCENT PASSING	
	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

Evaluation of Roundness

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:

Liquid Pavement Markings

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.

Binders

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. This line will feel rough like sandpaper. Figure 2.15 shows a stripe with good distribution but not enough glass beads.

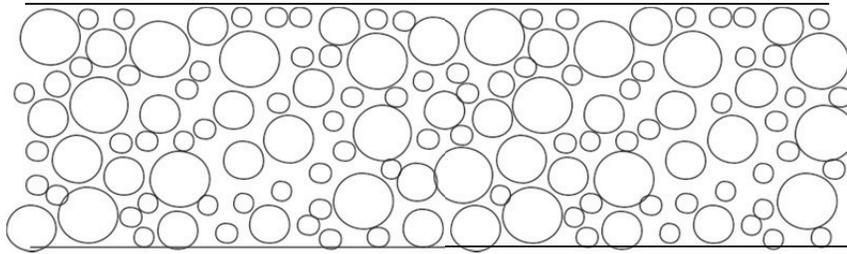


Figure 2.14
Representation of good bead distribution

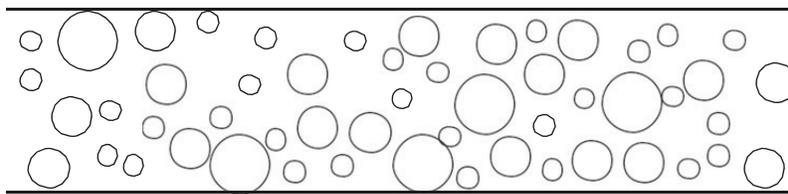


Figure 2.15
Too few beads

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.

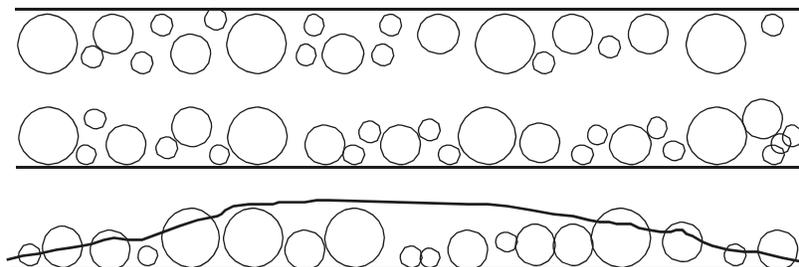


Figure 2.16
A contoured line

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.

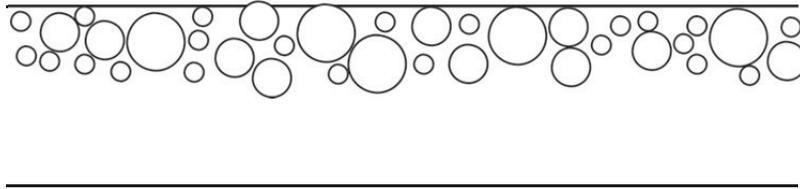


Figure 2.17
Beads on only one portion of the line

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

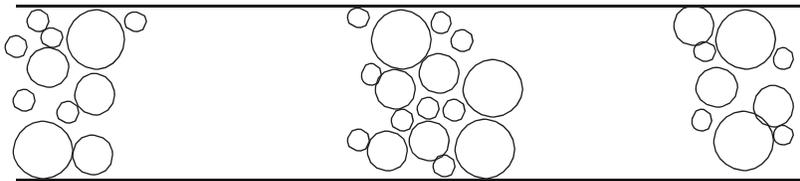


Figure 2.18
Line from a pulsating bead gun

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	<ul style="list-style-type: none"> • Bead gun out of alignment • Clogged bead gun 	<ul style="list-style-type: none"> • Poor night visibility 	<ul style="list-style-type: none"> • Adjust alignment of gun cap • Rebuild gun
Excessive bead use	<ul style="list-style-type: none"> • Worn gun needle, seat and orifice • Excessive glass bead pressure 	<ul style="list-style-type: none"> • Supply problems 	<ul style="list-style-type: none"> • Rebuild gun • Decrease pressure
Beads in middle of line	<ul style="list-style-type: none"> • Bead tank pressure too low • Bead gun “off” and “on” control screw not adjusted • Bead gun cap out of alignment 	<ul style="list-style-type: none"> • Poor night visibility 	<ul style="list-style-type: none"> • Increase Pressure • Adjust control screw • Align cap deflector • Change to a smaller tip
All beads buried	<ul style="list-style-type: none"> • Bead gun too close to paint • Bead gun angle too shallow • Excessive paint millage 	<ul style="list-style-type: none"> • Poor night visibility 	<ul style="list-style-type: none"> • Re-align bead gun • Adjust angle of bead gun • Check wet millage thickness
All beads on top of line	<ul style="list-style-type: none"> • Bead gun too far from paint gun 	<ul style="list-style-type: none"> • Loss of durability • Initial very bright line 	<ul style="list-style-type: none"> • Re-align bead gun
Pulsed bead application	<ul style="list-style-type: none"> • Bead tank pressure inadequate 	<ul style="list-style-type: none"> • Violates standard • Loss of effectiveness 	<ul style="list-style-type: none"> • Raise tank pressure • Rebuild applicator to increase pressure
Excessive amount of beads on road beside line	<ul style="list-style-type: none"> • Too much overlap of bead pattern on line pattern 	<ul style="list-style-type: none"> • Loss of reflectivity 	<ul style="list-style-type: none"> • Move bead gun closer to roadway

Figure 2.19
Reflective bead troubleshooting chart

References

See Appendix A for the following:

VDOT Road & Bridge Specifications

Section 234

Glass Beads for Reflectorizing Traffic Markings – This section references AASHTO M 247, Type 1 glass beads. The exception to this specification is that Virginia – DOT requires 80% of the beads to be round.

Section 704.03 (a) Procedures

(last paragraph)

See Appendix B for the following:

VDOT Manual of Instructions

Section 204.30 (a)

- (1) Sampling, Testing, and Approval
- (2) Acceptance (Requires Cert. I)

See Appendix C for the following:

Virginia Test Methods

VTM-94

Chapter 2 Knowledge Check

1. Reflective beads are used with pavement markings:
 - a) for skid resistance
 - b) to provide a filler for the paint
 - c) to enhance nighttime visibility
 - d) to produce a noticeable bump

2. The phenomenon where light is reflected directly back to the light source is called:
 - a) glow-in-the-dark
 - b) retroreflectivity
 - c) retro-fit
 - d) retro-illuminescence

3. For glass beads, the light bending phenomenon is known as:
 - a) the refractive index
 - b) the index card
 - c) index finger
 - d) the back-light ratio

4. The optimum embedment depth for reflective beads is
 - a) 20 to 40%
 - b) 50 to 60%
 - c) 30 to 40%
 - d) 80%

5. When inspecting pavement markings with regard to glass beads, which of the following criteria should be met?
 - a) Beads should be evenly distributed over the entire surface of the marking
 - b) 70 % of the beads should be buried, the remaining 30% shall be 50 to 60% embedded
 - c) Both a & b
 - d) None of the above

6. In order for glass beads to reflect light as intended, they must be:
- a) square
 - b) angular
 - c) buried
 - d) round
7. Proper bead distribution and depth are critical in ensuring a _____ line.
- a) durable and retroreflective
 - b) straight
 - c) properly colored
8. Correct glass bead application and embedment will result in the line feeling like:
- a) loose aggregate
 - b) smooth glass
 - c) sandpaper
 - d) all of the above