Comparative Study of Glass Bead Usage in Pavement Marking Reflectorization

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Prior research and field experience with a variety of pavement marking materials and glass beads for marking reflectorization are examined. The use of large glass beads to enhance the wet-night reflectivities of pavement markings was investigated, together with binder characteristics, to provide effective service life estimates, optimum bead-binder combinations, and cost-effectiveness comparisons. A literature review and a state-of-the-art survey conducted in southern states revealed that the cost different between large and standard glass beads was low relative to the amount of increased wet-night visibility offered by large glass beads. However it is not known with certainty how the high pavement temperatures and climatic conditions indigenous to the South will affect the service lives of markings with large glass beads. Field testing of large glass beads on roads with a relatively large number of wet-night accidents could enable determination of the effective service lives of bead-binder-pavement type combinations as well as expected accident reduction benefits.

The longevity of pavement marking material has a direct effect on the cost of pavement marking maintenance and user safety. The estimated cost of marking streets and highways in the United States each year is approximately \$475 million. This cost consists of about \$380 million for materials and the remaining \$95 million for their application. Dale (*1*) estimated that the quantities of marking materials used annually in the United States consists of the following:

- 37 million gal of traffic paint,
- 130,000 tons of glass traffic beads,
- 55,000 tons of thermoplastic marking materials, and
- \$55 million worth of other materials such as preformed tapes, raised pavement markers, polyesters, epoxies, and adhesives.

This is a significant amount of material representing not only a large monetary effort but also an extensive allocation of human energy and application equipment. Adequate pavement markings are, however, one of the highest-payoff, lowest-cost operational improvements that can be made to streets and highways. The FHWA Pavement Marking Demonstration Program of the 1970s demonstrated that improved transverse and longline pavement markings were effective in improving motorist safety. The improvement in safety was determined to be especially prevalent during nighttime and low-visibility conditions when the pavement markings serve to delineate required vehicle paths. The desirable delineation effect of pavement markings is accomplished by the principles of retroreflectivity.

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Glass beads have been used to make pavement markings reflective for approximately 50 years. If properly embedded in a striping material, glass beads have the ability to collect incident light and reflect part of that light back to its source. It is this ability that makes spherical glass particles ideally suited to making pavement markings visible at night. The performance of the glass beads is dependent on their embedment depth and size and environmental conditions. Research conducted during the late 1960s indicated that the optimum embedment of the glass beads is 60 percent of the bead diameter. It was also noted that during periods of adverse weather small glass beads often become submerged under a film of water. Light from vehicle headlights bounces off the water surface and is lost. It was concluded that the retroreflective capabilities of beads were significantly reduced during rainy or foggy conditions. In addition the different types of marking materials have different effective service lives with regard to their abilities to hold the beads in place and retain their retroreflectivity.

Many changes have occurred in the pavement marking industry in the past 20 years, especially in the increased availability of polymeric nonshrink binders as durable marking materials. In addition to the advent of nonshrink binders, good water-based paints have been developed; these paints have a higher solid content than typical alkyd paints. Alkyd paints have also changed to comply with the requirement for short no-track time. The extended durabilities of these markings, their greater thicknesses, and recent enhancements to the glass bead surface to improve adhesion have resulted in the ability to use larger glass beads than was possible in the past. The advantage of large glass beads is that they break through the water film on the road surface during adverse weather conditions, thereby reflecting light from vehicle headlights and making road markings more visible to the driver. In addition the use of large glass beads in conjunction with the enhanced binding properties and increased thicknesses of the new marking materials has the potential to provide an increased effective service life.

OBJECTIVES

The advent of new binding materials and the recognition of nighttime wet pavement retroreflectivity problems have resulted in efforts by researchers, materials manufacturers, and governmental agencies to identify the most advantageous pavement marking types. This paper summarizes the results of a literature review and state-of-the-practice survey conducted for a study whose primary objectives were to determine which combination of pavement marking and glass bead types (a) provides the longest effective service life and (b) is effective in increasing wet-night retroreflectivity.

PAVEMENT MARKING CHARACTERISTICS

Prior studies have demonstrated that in addition to the durability of the binder itself its effective service life is determined by the ability of the binder to retain the retroreflective material. Determination of the most appropriate binder therefore requires consideration of the type of application (i.e., longline or transverse), glass bead retention ability, traffic volumes, pavement surface type, and total cost over its service life. This section summarizes the durabilities, reflectivities, and advantages and disadvantages of the predominant binder types.

Traffic Paint

Traffic paints have been the most widely used pavement marking material since their introduction in the early 1920s. Usually classified by drying time—that is, instant dry (less than 30 sec), quick-dry (30 to 120 sec), fast-dry (2 to 7 min), and conventional (more than 7 min)—traffic paints comprise paint vehicle (alkyd, modified alkyd, chlorinated rubber, or water base), a solvent, a pigment, and glass beads. The drying time is determined by the specific ingredients used.

Durability is dependent on material composition, weather, application purpose, traffic density, and the type and condition of the application surface. The major problems encountered with traffic paints relate to bonding, reapplication over existing markings, and softening of the pavement surface, resulting in "bleeding" or discoloration of the paint. Bonding problems common to both concrete and asphalt pavements may be caused by surface contamination and the moisture content of the substrate. The use of water-soluble solvents and high temperatures can sometimes counteract such problems. Bleeding may be reduced by using fast-drying paints on asphalt surfaces, but adhesion may be adversely affected if solvents evaporate too rapidly and trap air between the paint and the pavement, a problem known as "bridging."

The relatively low initial cost, well-established technology, ease of installation, and readily available application equipment ensure the continued widespread use of traffic paints. They provide good dry-night visibility and a choice of drying times and are relatively safe to handle. The reduced drying time reduces labor costs and decreases traffic delays and potential accidents related to installation.

Paints have the shortest lives of all marking materials and offer poor wet-night visibility. Year-round delineation with one annual application is difficult to achieve in regions with severe winter climates, particularly on high-volume roadways. Paints with accelerated drying times also require more expensive striping equipment and cleaner pavement surfaces for successful adhesion and durability than those required for their longer-drying counterparts.

Thermoplastics

Thermoplastics are thick pavement marking materials consisting of a resin binder, coloring agents, an inorganic filler, and reflective glass beads. Proportioned and mixed in a factory, thermoplastics can be transported to job sites as solid slabs or as granular powder. Most commercial thermoplastics today use a blend of synthetic hydrocarbon resins, although the use of alkyd-based resin may become more widespread as its price decreases.

Southern states report an average thermoplastic service life of 10 years. Some thermoplastic markings were observed to last the life of the pavement, whereas other applications did not last for 1 year under heavy traffic conditions in northern climates. Thermoplastic durability is considerably better on asphalt than on concrete pavements. The most common problems encountered in northern climates are abrasion, shaving, and bond failure. Abrasion and shaving are principally caused by snow removal equipment. Since material failure is not involved, the solution is to change plowing procedures or use thinner marking materials. Bond failure results from improper installation (inadequate heating, dirty or oily pavement) and is common on concrete. On asphalt abrasion is related to the volume of traffic and the incidence of abrasive materials and studded tires. The poor performance of longitudinal markings is usually attributed to the presence of dirty or deteriorating pavement at the time of marking application.

Thermoplastic forms a relatively durable reflectorized marking. Its initial appearance is generally excellent, and reflectivity is sustained throughout its service life. Thermoplastic's dry reflectivity is generally equivalent to that of beaded paint, but its reflectivity is comparatively better under heavy rain. The crucial factor that affects its effectiveness is the bead application rate, although reflectivity can be diminished by dirt and plow damage. In a study conducted by the Texas Transportation Institute, reflectivity (on skip lines with or without primer) was excellent on asphalt after 2 years but was negligible on concrete because of bond failure.

Thermoplastic has an advantage over paint when year-round painting is not possible and when wet-night visibility is important. However it is a poor choice for transverse lines in areas with high traffic volumes and for longitudinal lines when turning traffic is common. Because of their thicknesses, thermoplastic markings are not suitable for use in regions with severe winter conditions because of their susceptibilities to snowplow damage.

Preformed Materials

Preformed markings are composed of high-quality plastics, pigments, and glass beads. These materials are applied to the pavement surface either by pressure or by heat. The beads are uniformly distributed throughout the film and form a firmly bonded layer on the surface.

The durability of a preformed marking depends primarily on pavement conditions and the number of pieces used. Durability is poor on old and deteriorating pavements, and especially on concrete. Furthermore since these materials can slide or shift, enhanced performance may be obtained by minimizing the number of pieces of preformed tape. One study in Kentucky reported a 4-year average useful life for preformed materials, although manufacturers guaranteed only 2 years for inlaid markings and 1 year for overlaid markings in snowbelt regions (*2*). After 2 years preformed markings in Virginia retained a satisfactory appearance and served adequately at (a) several urban intersections, (b) a section of an interstate highway where the tapes had been applied during resurfacing, and (c) on a highway with annual average daily traffic (AADT) of 25,000 and a high volume of turning traffic. State officials considered 3 years to be a conservative estimate of the life of preformed materials and predicted an 8-year life for at least one area.

The following are advantages of preformed marking materials:

- Their durability eliminates the need for annual or semiannual maintenance even in snowbelt regions.
- Installation is simple, safe, and clean.
- Their appearance and initial retroreflectivity are rated five or six times better than those of paint.
- Preformed tapes meet all of the requirements for color and conform to the *Manual on Uniform Traffic Control Devices.*
- Preformed tapes adhere well, especially when they are laid on new pavements.
- They are easy to repair because pieces adhere well to each other.
- They eliminate the need for major traffic disruption during installation.

Epoxy

Epoxy is a solid, two-component, chemically reacted system. It is safe to both handle and apply since it has no solvents that can evaporate and requires low heat. Epoxy is abrasion resistant and durable and adheres well on both asphalt and concrete.

Epoxy's durability has proven to be good to excellent in several tests in Minnesota. In one test epoxy lasted for over a year on roads with high AADT, in comparison with 3 months or less for traffic paint, and was effective even 5 years later. At present durability of 3 years has been proven on roads with low AADT. Failures occur when pavement surface conditions are poor, when large volumes of crossing or weaving traffic exist, and when application or quality control requirements are not properly followed. Failures associated with epoxy are most likely to be one of the following:

- Chipping caused by surface contamination or poor temperature control, which is apparent within days.
- Color change caused by the lack of pressure control, improper mixing, or improper bead application.
- Wheel tracking resulting from incorrect bead application.

Under low- to medium-AADT conditions epoxy retroreflectivity is excellent when new and is still acceptable after 3 years. Although daytime delineation has been found to drop after 2 years, nighttime delineation was more than adequate even after three northern winters. Epoxy is safe to handle and apply and has good color and bead retention, excellent retroreflectivity, good abrasion resistance, and good adhesion on both asphalt and concrete. Epoxy can be applied on damp pavement and is applied like paint.

The disadvantages associated with epoxy are mostly related to installation procedures and equipment. They include the following:

- The material is unforgiving; that is, there is no room for sloppy workmanship.
- Control of the pumping system is critical; with present formulations temperature control during application is critical.
- Placement in urban, low-speed situations must be protected to prevent tracking.
- Special application equipment is required, although not as much as is required for thermoplastics.
- Placement and drying times are long.

Polyester

Polyester is a two-component thermosetting material consisting of a resin and a catalyst. The resin resembles standard traffic paint, and the catalyst is usually on organic peroxide, methyl ethyl ketone peroxide (MEKP). MEKP must be handled with care because it can cause burns and its fumes are dangerous. Polyester has a long drying time and can be applied over old paint.

One study stated that one application of polyester lines rated equal in color to painted lines after 3 years, although the paint had been applied three times (*2*). In another study the polyester line on a highway with an AADT of 20,000 appeared grayer in color than paint during the daytime, but it was superior to paint at night and remained effective for 8 years. Polyester has been successful when used for center and lane lines and has few reported problems when applied over old paint. Tests show that polyester lines applied at thicknesses of 7.5 and 15 mils are equally durable. On the basis of experience with polyester in Ohio, the following service lives can be expected when polyester is applied on good asphalt pavement:

- 3 to 4 years, centerline, AADT of up to 10,000,
- 1 year, centerline, AADT of up to 10,000 with heavy trucks and curves, and
- 3 to 4 years, lane line, AADT of up to 24,000.

The biggest problem with polyester markings is abrasion. In addition bond failure can occur if polyester is applied over an emulsion seal because of tracking, poor weather, oily asphalt, or poor equipment. The "Swiss cheese" effect, which occurs on oily asphalt if polyester material is applied too soon after paving, can be avoided either by waiting for 2 weeks after paving is completed or by first striping with fast-dry paints.

The use of 15-mil wet thickness and 16 to 20 lb of standard drop-on beads per gal (1.9 to 2.4 kg/L) of polyester material provided good reflectivity in one 3-year study and superior reflectivity for 8 years in another study. In addition to performing consistently well for more than 3 years, polyester material does not require more care than standard traffic paint or a minimum pavement temperature for application. It is low in cost and can be applied over old paint.

Polyester has several disadvantages: poor performance on concrete, bond failure because of abrasion, and long drying time. Also since the resin-catalyst mixture does not stabilize immediately, some time must be allowed before striping begins. The application equipment can be troublesome, and one must handle the catalyst cautiously and use protective goggles and gloves. For the best results the air temperature must be 50°F and application must wait for 2 weeks after paving unless a primer is first applied.

Epoflex

Epoflex is an epoxy thermoplastic material consisting of a binder (60 percent solids, 40 percent liquid resin), pigment, a calcium carbonate filler, and premixed glass beads to provide continuous retroreflectivity as the material wears.

Epoflex has provided satisfactory durability in field trials on both asphalt and concrete pavements in California, Colorado, Minnesota, and Texas (*2*). In most cases it is many times more durable than paint and is at least twice as good under test conditions in which the AADT was 27,000, there was a high volume of trucks, and studded tires were used. Epoflex applied over existing paint endured as well as that applied on bare pavement. The following conclusions about epoflex were based on these tests:

- Its service life is equivalent to that of 10 applications of paint on concrete and asphalt pavements in warm climates (no snowplowing) under both moderate and heavy traffic conditions.
- The service life of epoflex on asphalt is twice its service life on concrete in cold climates and with moderate traffic conditions.

On a commuter route with an AADT of 42,000 epoflex demonstrated excellent bead retention and no discernible wear after 2 years, whereas similar applications of traffic paint showed clear signs of deterioration. After a year in Minnesota, which included a severe winter, epoflex still provided satisfactory day and night delineation. Glass beads are dropped on during application to provide the initial retroreflectivity, whereas premixed beads ensure the continuance of retroreflectivity. Specially treated chemical-resistant beads provide better bead retention.

The major advantages of epoflex are its lack of a track time (less than 5 sec), lack of volatile components, low cost, and simplicity of formulation. It provides an extended service life and good reflectivity on both asphalt and concrete and can be applied at temperatures down to freezing. Epoflex has three major disadvantages: the high installation temperature required, its incompatibility with existing striping equipment, and the precise timing required for drop-on bead application.

LITERATURE REVIEW

A literature review was conducted to trace the development of bead-binder matching and bead gradation selection and to identify previous studies of the nighttime wet surface effectiveness of various pavement marking materials. The studies reviewed here represent prior research and experience with various binders, bead types, and bead sizes.

Pocock and Rhodes (*3*) investigated the principles of glass bead reflectorization and studied the effects of application procedures, bead gradations, and the refractive index of the beads on retroreflectivity. That study indicated that an advantage of using small glass beads is that they provide greater reflective area per pound than larger beads. The study did not, however, consider the lower wet-night reflectivity that results from small glass beads submerged under a film of water.

Dale (*4*) investigated the effectiveness of a silicone-based bead surface layer in improving roadway delineation under both dry and wet conditions. The silicone treatment resulted in reduced clogging of bead-dispensing equipment as well as reduced bead overembedment into the pavement marking material. That study also determined that the optimum depth of bead embedment for retroreflection ranged from 55 to 60 percent of the bead diameter. Lower embedment depths resulted in the premature loss of adhesion between bead and binder, whereas greater depths resulted in the loss of retroreflective efficiency. Glass beads larger than those currently used were suggested as a way of overcoming the problem of the loss of retroreflectivity during wet conditions, and it was noted that the thickness of the paint film would need to be increased to provide the necessary binding depth for the beads.

In subsequent work Dale (*5*) questioned the appropriateness of the bead gradations used for drop-on application. He concluded that the use of various bead sizes in a constant thickness of paint results in the provision of efficient retroreflectivity by only a small percentage of the beads. The rationale behind the use of a gradation of mixed sizes is that pavement marking paint gradually fails by abrasion. As the paint wears away smaller beads are continuously exposed, thus providing sustained retroreflectivity. However it was noted that paint often does not fail by abrasion but instead chips away. In that case a smaller quantity of large beads could provide higher retroreflectivity at considerable cost savings over that provided by larger quantities of different-sized beads.

An NCHRP Synthesis (*6*) evaluated various pavement marking materials and how the method of application affected their serviceability. The authors discussed the difficulty of deciding the optimum bead gradation because of wide variations in environmental conditions, application methods, and control of materials. The survey results reported herein indicated that two states preferred the use of premixed beads in paint because of its convenience of use and the uniform distribution of beads in the paint film. However 80 percent of state agencies used drop-on beads because of lower nozzle wear, faster drying time, and the decreased need for paint agitation. The survey determined that the predominant bead gradation used by states was U.S. sieves No. 30 to No. 80.

A research report by the Organization for Economic Cooperation and Development (OECD) (*7*) indicated the conditions and factors that should be considered in the selection of appropriate materials for various circumstances. An embedment of approximately 60 percent of the bead diameter for optimum retention and reflectivity with a bead gradation of between U.S. sieves 40 and 80 (0.42 to 0.177 mm) was suggested.

Gillis (*8*) reported on a study that evaluated epoxy, polyester, and thermoplastic resins as pavement marking materials. The study demonstrated that epoxy markings provided adequate delineation for both day and night conditions more than 2 years following installation. It was also found that epoxy provided better retroreflectivity than both paint and thermoplastic markings.

McGrath (*2*) summarized evaluations of six durable pavement marking materials. Bead gradations of U.S. sieves 20 to 80 were used in thermoplastic markings, which provided excellent reflectivity on asphalt after 2 years but resulted in poor reflectivity on concrete because of bond failure. Preformed materials performed satisfactorily for 4 years, epoxy performed satisfactorily for 2 years, polyester performed satisfactorily for up to 8 years, and epoflex performed exceptionally well even with high traffic volumes and warm climates.

A 1988 NCHRP Synthesis (*1*) summarized pavement marking needs, different types of pavement marking materials, and methods of preparing the pavement surface before marking. That study investigated two types of paint (solvent based and water based), thermoplastics, thermosets (polyester and epoxy), and marking tapes. The cost-effectiveness of the different pavement marking types was discussed, and life expectancy curves were provided for markings on both asphalt and concrete pavements.

O'Brien (*9*) performed a laboratory investigation of the embedment characteristics of drop-on moisture-proofed and uncoated glass beads and their associated retroreflectivities in combination with various types of hot-applied thermoplastic markings. The study concluded that moisture-proofed drop-on beads give excellent retroreflectivity and that the retroreflectivity of the standard bead gradation was enhanced by increasing the proportion of larger beads.

Kalchbrenner (*10*) described tests of large beads (VISIBEADs) in pavement markings conducted by Potters Industries. Demonstration projects were set up in 25 states encompassing seven geographical areas to investigate a variety of binders, road types, pavement types, and application methods. Laboratory tests concluded that the optimum bead size for good wet-night reflectivity ranged from U.S. sieves 10 to 20, depending on the binder. The field test and demonstration projects showed that large glass beads provided significantly superior retroreflectivities compared with standard bead sizes for a variety of thin and thick binders. That study also suggested bead gradation specifications for single- and dual-drop marking systems.

Mendola (*11*) conducted a study to evaluate the retroreflectivity performance of VISIBEADs in epoxy paint at a 20-mil thickness. That study used photometric and visual tests to compare large glass beads in epoxy paint and standard beads in traffic paint. The tests concluded that large beads produced significantly better retroreflectivity than standard beads and that the cost difference between large and standard beads is relatively low when compared with the increase in wet-night visibility.

King and Graham (*12*) evaluated the visibilities of eight pavement marking materials for the state of North Carolina. The study also evaluated epoxy markings reflectorized with large glass beads and concluded that the larger beads improved the wet-night visibilities of the markings by a factor of two, or more than that for adjacent standard bead lines.

Griffin (*13*) conducted a study for the Colorado Department of Highways to review the performances of pavement marking materials. From that study Griffin concluded that the VISIBEADs met the specifications of the department but were susceptible to loss because of snowplowing operations.

A 1989 *Better Roads* survey (*14*) reported on the pavement marking types preferred by highway departments and some of the problems experienced with them. That survey reported favorably on the performance of VISIBEADs during wet weather.

The Ohio Turnpike substituted VISIBEADs for standard beads in a large glass bead testing project over a wide range of traffic volumes, roadway geometrics, and pavement conditions (*15*). Preliminary results indicated that average reflectivities were well above the minimum acceptable levels. Joint sealing and snowplowing were identified as two major causes of reflectivity loss. It was estimated that 25 to 30 percent of the pavement markings were damaged by snowplowing and another 5 to 10 percent were damaged by joint sealing.

STATE-OF-THE-ART SUMMARY

Considerable effort has been expended in determining which type of pavement marking material has the most cost-effective service life. As expected the service life is dependent on the application procedures, material components, pavement surface, traffic intensity, and environmental conditions. Although some studies have addressed larger bead sizes for increasing wet-night retroreflectivity, specific information regarding the performance of particular bead size and pavement marking material combinations is scarce.

A survey was conducted to determine the experiences of southern states with different glass bead sizes and various pavement marking materials. The survey was mailed to southern state highway agencies, agencies conducting research on large beads, and paint and bead manufacturers. The results of the survey are summarized below.

Pavement Marking Materials Used

Thirty percent of the agencies that used paint used both water-based and alkyd-based paints; 30 percent applied alkyd-based paints only, whereas 40 percent did not specify the type of paint used. Eighty percent of the responding agencies employed paints for both longline and transverse markings; 10 percent used paint only for transverse markings, whereas another 10 percent used paints only for longlines on both asphalt and concrete pavements. Eighty percent of the agencies used thermoplastics at least on an experimental basis, 40 percent used thermoplastics for both longline and transverse markings, 30 percent used thermoplastics on asphalt pavements alone, and 10 percent used thermoplastics on an experimental basis alone.

Eighty percent of the responding agencies used preformed material on both asphalt and concrete pavements. Seventy percent used preformed material for both longline and transverse markings, and 10 percent used preformed material only for transverse markings. Ninety percent of the responding agencies employed epoxy markings on their roadways. Seventy percent used epoxy for longline and transverse markings, 10 percent used epoxy on concrete pavements alone, and 10 percent used epoxy for longlines on asphalt pavements alone.

Forty percent of the responding agencies used polyester for pavement markings. Ten percent used it for longline and transverse markings on both asphalt as well as concrete, 10 percent used it only for longlines on both asphalt as well as concrete, and the remaining 20 percent used polyester for longlines on asphalt alone. Fifty percent of the responses indicated the use of epoflex. Ten percent of the agencies applied epoflex for longline and transverse markings on both asphalt and concrete, 20 percent used it for longlines on both asphalt and concrete, and the remaining 10 percent used it for longline and transverse markings on asphalt alone.

Reapplication Schedule

All agencies reported using paint as a marking material. Of these 20 percent used water-based paints, with a reapplication schedule ranging from 6 to 12 months. Seventy percent did not specify the paint base used. These agencies had a reapplication every 12 months for longlines on asphalt, 6 months to 4 years for transverse markings on asphalt, 6 to 12 months for longlines on concrete, and 6 months to 4 years for transverse markings on concrete. Ten percent of the agencies used alkyd-based paint with a reapplication schedule of 6 months for longline and transverse markings on both asphalt and concrete pavements.

Thermoplastics were used by 10 percent of the agencies for longline and transverse markings on both asphalt and concrete, with a reapplication every 3 years. An additional 10 percent used thermoplastics for longlines on both asphalt and concrete, with reapplication once a year, whereas 10 percent used thermoplastics for longlines on asphalt, with reapplication every 5 years, and for transverse markings on asphalt, with reapplication every 3 to 4 years. Twenty percent of the agencies reported the use of thermoplastics, 10 percent without specifying a reapplication schedule and 10 percent having let out the maintenance to contract.

Thirty percent of the agencies responding used preformed materials for longlines and transverse markings on both asphalt and concrete pavements, with reapplication every 2 to 5 years; 10 percent of the agencies used preformed materials for transverse markings on both asphalt and concrete, with reapplication every 3 years; and 20 percent used preformed markings for longlines on asphalt and concrete, with reapplication every 2 to 8 years on asphalt and 1 to 5 years on concrete. An additional 10 percent used preformed materials for longline and transverse markings on concrete but let out the maintenance to contract.

Fifty percent of the agencies responding used epoxy for longline and transverse markings on both asphalt and concrete, with reapplication every 2 to 5 years; 20 percent used epoxy for longlines on asphalt and concrete, with reapplication every 2 to 4 years; and 10 percent used epoxy for longlines on asphalt, reapplying it every 2.5 years. Ten percent of the agencies employed epoxy on new construction projects.

Ten percent of the agencies used polyester for longlines on both asphalt and concrete, with a reapplication every 2 years. The remaining 30 percent applied polyester for longlines on asphalt, with reapplication every 6 months to 2 years. Of the agencies that used epoflex, 30 percent used epoflex for longlines on asphalt, with the prevalent conclusion that the material was unsuitable for pavement marking. The remaining 20 percent either did not indicate the type or area of use or reported that the maintenance of the markings was let out to contract.

Special Problems with Marking Materials

Seventy percent of the agencies reported encountering problems with paint. Thirty percent noted that paints had a poor service life, 10 percent reported the unavailability of large quantities of chlorinated rubber, 10 percent said that the slow drying times of paints led to damage claims, whereas 10 percent indicated that the paint markings faded when used for longlines on asphalt pavements. An additional 10 percent indicated that paints performed as expected, with only localized problems occurring.

Fifty percent of the responding agencies reported problems with thermoplastic markings. Ten percent reported adhesion problems with longline and transverse markings on both asphalt and concrete. This problem was attributed to the pavement condition and the method of application. Snowplow damage to longline and transverse markings on asphalt as well as poor adhesion for longlines on concrete pavements were reported as problems by 10 percent of the agencies. Ten percent reported bond failure of longlines on asphalt because of snowplowing, whereas another 10 percent reported cracks in longlines on asphalt and bond failure of transverse markings on concrete because of snowplowing. A final 10 percent indicated that thermoplastics had poor service lives on concrete pavements.

A large portion, 70 percent, of the responding agencies encountered problems with the use of preformed materials as pavement markings. Ten percent reported problems with adhesion and the shifting of longlines and transverse markings on both asphalt and concrete pavements; 10 percent reported the shifting of longlines and another 10 percent reported the shifting of transverse markings on asphalt. Ten percent of the agencies indicated that they encountered retention problems and snowplow damage to markings placed on concrete. Another 20 percent reported the loss of retroreflectivity on both asphalt and concrete, with a final 10 percent reported peeling and adhesion problems at crosswalks.

Seventy percent of the responding agencies reported encountering problems with the use of epoxy as a pavement marking material. Most of these were concerned with discoloration, yellowing or graying, of the white epoxy markings. Thirty percent reported a yellowing or graying of longlines on asphalt, 10 percent noted graying of longlines and transverse markings on concrete, whereas another 10 percent reported fading and discoloration of longlines on concrete. Dead spots (sunken beads) were reported by 10 percent of the agencies. This problem was remedied by using larger beads, but this in turn led to mixing problems. A final 10 percent of the agencies reported some early adhesion problems on both asphalt as well as concrete, but were generally satisfied with the performance of epoxy as a marking material.

Half of the agencies that employed polyester reported problems with its use. The long drying times of longlines on asphalt and concrete and the short service lives of longlines on asphalt were the two principal problems encountered with the use of polyester. Forty percent of the agencies reported adhesion problems and a short service life of epoflex. Of these, 10 percent reported adhesion inadequacies of longline and transverse epoflex markings on both asphalt and concrete, and another 10 percent reported the total failure within 1 year of epoflex longlines on asphalt and concrete. A final 20 percent indicated adhesion problems and a poor service life of epoflex longlines on asphalt.

Marking and Bead Application

The predominant application rate of drop-on, standard-sized beads reported was 6 lb/gal of paint and 20 to 25 lb/gal of epoxy. Ten percent of the agencies reported a drop-on bead application rate for VISIBEADs of 12 lb/gal of paint and a mix of 12 lb of standard beads and 15 lb of VISIBEADs per gal of epoxy by using drop-on application.

Bead Surface Treatments

Specific bead treatments for moisture proofing and adhesion were reported by 40 percent of the agencies. Twenty percent employed moisture proofing treatments; 10 percent used adhesion coatings for beads in epoxy and flotation beads in thermoplastics. A final 10 percent applied a silane coating for paint beads.

Use of Large Beads

All of the responding agencies had experience with the use of large glass beads, at least on an experimental basis. Ten percent used glass beads of sizes 16 to 50 at an application rate of 12 lb/100 ft^2 of 120-mil-thick thermoplastic. The remaining agencies employed large glass beads of sizes 12 to 50 on epoxy at a 15- to

20-mil thickness. Ninety percent of the agencies found the retroreflectivity level of the large glass beads to be satisfactory, and the remaining were still evaluating it.

Effective Bead-Marking Combinations

Eighty percent of the responding agencies provided information on marking material and glass bead combination. Epoxy markings were used by 40 percent for longlines and by 30 percent for transverse markings in urban and rural areas. Thermoplastics were used by 30 percent for longlines and transverse markings and by 20 percent in urban areas. The glass beads mainly employed for epoxy were VISIBEADs of sizes 14 to 20, a mixture of standard and large beads for thermoplastics, whereas standard-sized beads were used with paints.

COMPARATIVE APPLICATION COSTS

The cost estimates contained in this section were obtained from McGrath (*2*) unless otherwise identified. Paint costs approximately \$5 to \$10/gal (\$1.31 to \$2.63/L), and installation costs range from \$0.03 to \$0.05/ft (\$0.09 to \$0.18/m) for a 15-mil (4-in.; 10.2-cm) line. Although cost per installed foot for paint is reasonable, the apparent cost savings are often lost because of the required frequency of application. The cost of thermoplastics ranges from \$0.30 to \$0.40/ft (\$0.92 to \$1.22/m) for a 4-in. (10.2-cm) line and is 5 to 10 times higher than that of paint because of material and installation costs.

The use of preformed tapes for lane lines is too new to have produced good benefit-cost statistics, with costs ranging from \$0.56 to \$0.90/ft (\$1.71 to \$2.75/m). Virginia paid \$0.60/ft (\$1.83/m) for a 4-in. (10.2-cm) line and expected the price to decrease. Only on the basis of the costs of materials and installation, state officials estimated that preformed tape placed on a section of Interstate highway must last approximately 8 years to offset the cost of traffic paint. Although high cost has been reported as a disadvantage for preformed markings, it is quick and easy to install, and application equipment is readily available.

Epoxy has an initial cost six times higher than that of paint, although its extended service life makes its cost comparable to that of paint. On the basis of a 4-year projected cost study under various traffic volume situations, the Minnesota Department of Transportation found that epoxy outlasted paint, thermoplastic, and polyester materials by factors of two to eight. New epoxy formulations and redesign of equipment are expected to reduce costs (*2*). Polyester compares with other durable materials, as shown in Table 1.

Epoflex costs approximately \$25/gal, compared with \$4/gal for traffic paint. A 4-in. line of epoflex at a thickness of 15 mil costs \$0.21/ft, which is \$0.16/ft more than paint applied at 10 mil dry. Since epoflex has twice the service life of paint in cold climates, however, it actually costs less in the long run. The cost of producing epoflex from raw materials is expected to decrease because of the simplicity of its manufacture. Although the cost of converting stripers designed for paint can be significant, epoflex's service life under almost any condition is expected to rapidly amortize this cost over a short time.

TABLE 1 Comparative Costs of Durable Pavement Markings

	Marking Cost ($ per foot)		
	Polyester	Fast-dry Paints	Epoxy
Edge line	0.12	0.03	NA
Lane line	0.15	0.04	0.40
Center line	0.20	0.05	0.50

SUMMARY

Potters Industries conducted the initial research that has resulted in the modern large glass bead technology. This technology tailors the bead coating and size to the type and thickness of the pavement marking material. Experience with large beads indicates that they become an integral part of the wearing surface and actually extend pavement marking life in high-traffic areas. Since the effective service life of pavement markings is, however, dependent on more variables than traffic wear, the planned lives of materials with large beads should be considered equal to those with the same marking materials with standard beads. Large beads, even when worn by traffic and abraded by dirt, provide greater retroreflectivity values than new standard beads.

Advances in two pavement marking areas have resulted in the ability to use large bead sizes. The first is in new pavement marking materials, applications systems, and enhancements to existing marking materials that have resulted in the ability to apply thicker layers of material. The high quantity of solids results in a greater dry thickness with acceptable drying times. The second area of advancement is in bead manufacture. Potters Industries has devised a system of large bead size and bead coatings that is optimal for each type of binding material. The result is beads manufactured for a particular type of pavement marking material.

Since the size and bead coating varies in accordance with the type of pavement marking material used, there exists variation in applied cost. Accompanying this variation in cost is the variation in service life because of durability of the pavement marking material. Although there have been claims that the larger bead sizes become part of the wearing surface and thus increase pavement marking life, it is generally found that pavement markings with larger beads will not last longer than pavement markings with regular bead sizes. The higher cost of larger beads, coupled with the limited life of paint, results in paint not being a cost-effective medium for such beads. A possible exception to this would be in areas of high precipitation that are experiencing a relatively large number of accidents attributable to poor nighttime delineation. Even in this instance, however, the agency would experience increased cost-efficiency by using more durable binders.

Much of the current knowledge on the effectiveness and service lives of large beads is based on the experience of states with climatic conditions that are drastically different from those of the southern United States. The study described here revealed that the large beads are effective in increasing the retroreflectivities of pavement markings in wet-night conditions. However it is not known with certainty how the high pavement temperatures and other climatic conditions indigenous to the South will affect the effective service lives of markings. It would be advantageous to test large beads on rural roads that experience a relatively large number of wet-night accidents. The proper selection of test segments will enable determination of accident reduction benefits in addition to marking visibility enhancement. No studies that have attempted to quantify accident reductions because of large bead application have been identified.

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REFERENCES

1. Dale, J. M. *NCHRP Synthesis of Highway Practice 138: Pavement Markings: Materials and Application for Extended Service Life*. TRB, National Research Council, Washington, D.C., 1988.
2. McGrath, M. A. *Durable Pavement Marking Materials Workshop*. Report FHWA-TS-81-221. FHWA, U.S. Department of Transportation, 1981.
3. Pocock, B. W., and C. D. Rhodes. Principles of Glass Bead Reflectorization. In *Highway Research Bulletin 57*, HRB, National Research Council, Washington, D.C., 1952.
4. Dale, J. M. *NCHRP Report 45: Development of Improved Pavement Marking Material—Laboratory Phase*. HRB, National Research Council, Washington, D.C., 1967.
5. Dale, J. M. Traffic Marking Beads—Are the Gradations Right? *Better Roads*, Vol. 39, No. 1, Jan. 1969.
6. *NCHRP Synthesis of Highway Practice 17: Pavement Traffic Marking: Materials and Application Affecting Serviceability*. HRB, National Research Council, Washington, D.C., 1973.
7. *Road Markings and Delineation*. OECD Road Research Group Report. Organization for Economic Cooperation and Development, Feb. 1975.
8. Gillis, H. J. Durable Pavement Marking Materials. In *Transportation Research Record 762*, TRB, National Research Council, Washington, D.C., 1980.
9. O'Brien, J. Embedment and Retroreflectivity of Drop-On Glass Spheres in Thermoplastic Markings. In *Transportation Research Record 1230*, TRB, National Research Council, Washington, D.C., 1989.
10. Kalchbrenner, J. Large Glass Beads for Pavement Markings. In *Transportation Research Record 1230*, TRB, National Research Council, Washington, D.C., 1989.
11. Mendola, A. A. *Comparative Study of the Performance and Cost Effectiveness of Large Glass Beads and NJDOT Standard Glass Beads in Epoxy Traffic Paint*. Final Report. New Jersey Department of Transportation, Sept. 1990.
12. King, L. E., and J. R. Graham. *Evaluation of Pavement Marking Materials for Wet Night Conditions*. Report FHWA/NC/89-003. FHWA, U.S. Department of Transportation, Oct. 1989.
13. Griffin, R. G. *Pavement Marking Materials*. Report CDOH-DTD-R-90-4. Colorado Department of Highways, Denver, July 1990.
14. Striping and Marking: What Works Best? *Better Roads*, Vol. 59, No. 4, Dec. 1989.
15. DePaulo, D. C. Ohio Tests Large Glass Striping Beads. *Better Roads*, Vol. 60, No. 4, April 1990.

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