Large Glass Beads for Pavement Markings

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Many changes have occurred in the pavement marking industry in the past 20 years, especially the commercialization of polymeric nonshrink binders (epoxy, polyester) as durable striping materials. These materials are normally applied at thicknesses between 15 and 20 mils. Thermoplastic materials are used with application techniques and resin systems unknown 20 years ago. These materials are applied at thicknesses between 40 and 125 mils. It became apparent that as striping line durability and net line thickness increased, glass bead characteristics had to change. The extended durability of these films has shown the need for bead surface treatments that improve bead adherence to the binders. The rheology and wet film application of these new materials indicate a need for a large-diameter glass bead. Use of larger beads fits the theoretical requirement of bead embedment and binder thickness for optimum retroreflectivity. The author explains that when pavement markings are viewed as a system (i.e., bead size and surface treatment are compatible with a specific striping material), improved reflective performance can be obtained with the added benefit of wet pavement/nighttime reflectivity.

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 toward its source. It is this ability that makes these small, spherical glass particles unique and ideally suited to make pavement markings visible at night.

BACKGROUND

The principles of retroreflectivity were first studied by Pocock and Rhodes (*1*) in 1952 and subsequently demonstrated by Dale in a 1967 NCHRP Report (*2*). The work was done at the Southwest Research Institute as part of NCHRP Project 5-5: Nighttime Use of Highway Pavement Delineation Materials. Dale's work was further verified and studied by Vedam and Stoudt and published in an appendix to work by Shuler (*3*). The objective of Dale's research was to study ways of improving delineation of roadways under wet and dry conditions either by improving techniques using then-existing materials or by developing new materials and techniques. It was noted that during periods of adverse weather, the small glass beads used as reflective media often became submerged in a film of water. Light from headlights bounced off this water surface and was lost. It was concluded that the retroreflective capabilities of highway beads that functioned well when the roadway was dry were significantly reduced during rain and often during foggy or misty conditions as well.

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As part of the background research for his work, Dale studied the performance of available marking materials in the field, considering both wet and dry conditions, levels of precipitation, and road characteristics. He also studied the performance of glass beads in the laboratory and demonstrated that the optimum embedment for reflectivity of glass beads in a binder was 60 percent of the bead diameter. As a result of this research, an article was published in the January 1969 issue of *Better Roads* (*4*) that alluded to the fact that only a small percentage of drop-on beads were efficient retroreflectors because only a small percentage were optimally embedded to 60 percent of their diameter. The conclusion was that a narrower gradation with a smaller drop rate would be a more efficient solution.

Although this argument was advanced, specifications remained virtually unchanged. The question of optimum gradation—that is, the use of a wide size range (from 20 to 80 mesh) or a narrowed gradation (from 40 to 80 mesh)—was answered by Ritter (*5*). He showed that both for initial and long-term reflectivity, the typical 20 to 80 mesh size is preferred. This was based on the following factors:

- Striping equipment does not apply a uniform film thickness—a nominal application of 15 mils could realistically be 15 ± 5 mils;
- Materials applied at 15 mils wet will dry to 8 mils, assuming 50 percent solids in paints;
- A sphere should be embedded to 60 percent of its diameter for optimum durability and visibility.

The first and third factors above are still valid; however, the assumption that striping materials always dry to 50 percent of their wet film thickness is no longer valid. In the early 1970s, work was initiated on chemically reactive, 100 percent solid, two-component striping materials. The state of Minnesota, with the H.B. Fuller Company, did major developmental work on 100 percent solid epoxy striping material (*6*). This material is typically specified at 15-mil wet film curing to 15 mils. The beads specified are the same as those for paint binders, but they are applied at a rate of 25 lb/gal versus 6 to 8 lb/gal in order to achieve quicker no-track and good reflectivity. This loading of beads has been noted to inflate the total line thickness to 35 to 40 mils (*7*).

Concurrent with the initial work that was being done on epoxy, reactive polyester material was being tested in Minnesota. The material performed well and, combined with good promotion by local manufacturers, became an accepted striping material in Ohio. From Ohio, use spread to neighboring states and beyond. As with epoxy, reactive polyester is also typically specified at 15 mils applied, curing to almost the same film thickness. Bead size is the same as that specified for paint binder systems, but the application rate is increased to 18 to 20 lb/gal. Again, this is to achieve quicker no-track and good reflectivity, because some standard beads are enveloped in the thicker binders.

In addition to the development of field-reacted materials, hot-applied thermoplastics have significantly increased in use. Applied film thicknesses range from 40 to 125 mils. In his 1967 report on the NCHRP project, Dale noted that the practice was to use essentially the same drop-on bead gradation in thermoplastics as was being used in paints. This is still true today, although Dale's recommendations at the time were for the use of larger-size beads to project up through submerging films of water and achieve improved wet reflective performance in thermoplastics. This was an apparent solution to the problem of wet reflectivity and was "begging" for application.

In addition to the advent and increased use of nonshrink polymeric binders, other changes have been made in paint chemistry in recent years. Environmental concerns have encouraged the development of good water-based paints with higher solids content than typical alkyd traffic paint. Alkyd paints have also changed to comply with the requirement for short no-track time, affecting the final film thickness.

Thus, over the years there has been a general broadening of binder types and a net increase in thickness of paint or binder film without a commensurate increase in bead size to maintain the optimum 60 percent embedment.

A number of approaches to improve performance have been taken with the typical 20 to 80 mesh beads that have worked so well for so long. For example, wicking around a 20-mesh bead would beneficially change net embedment from 30 percent to 60 percent. However, the same wicking phenomenon would totally submerge an 80-mesh bead. Treating beads with a nonadherent silicone coating would prevent wicking but would also result in poor durability. Thus, silane coupling agents were developed that gave controlled wicking as well as good bead adhesion to the binder system for the 20-80 beads.

Laboratory tests with reactive striping materials (epoxy and polyester) using the bead push-out test, as described by DaForno of Potters Industries at the 1976 TRB Annual Meeting, showed improved glass-binder adhesion with silane coupling agents. In epoxy material, Potters' AC-04 surface treatment improved bead-epoxy adhesion five times over moistureproof-treated beads and was 25 percent better than uncoated beads. In polyester materials, Potters' AC-02 surface treatment improved bead-polyester adhesion 10 times over moistureproof-treated beads and was 50 percent better than uncoated beads. Over time, field experience has verified the value of a proper bead-binder marriage and confirmed the improved performance of adherence coatings.

Silane coupling agents are binder selective. One silane is required for epoxy materials, and another silane is reactive with polyester materials. Because thermoplastics are not a specific chemically reactive material but a generic form of hot-melt adhesives, materials varied from different manufacturers, requiring specific silanes to optimize bead-binder embedment and adhesion.

Still missing, however, was a large-enough bead to give wet pavement/nighttime visibility consistently over the useful life of the line, particularly in the more durable line binder systems that were thicker than conventional paints.

DEVELOPMENT OF THE LARGER GLASS BEAD

In 1984, Potters began experimenting with larger glass beads both in the laboratory and at a field test site in northern New Jersey. It was soon recognized that the combination of a controlled environment and real-world use provided valuable insights into proper bead size and functionality.

LABORATORY PERFORMANCE

Potters' laboratory work with larger-sized beads in pavement markings has included extensive research at the Thomas K. Wood research facility. Better known as Potters' "rain tunnel," the facility provides rain simulation at three different rates (¼, ½, and ¾ in./hr) on a 26-ft wide crowned two-lane road. A simulated, textured road surface was developed as part of the program. Finally, a laser retroreflectometer was developed that facilitated measurement of line performance in the rain. Thus, the wet reflective performance of pavement marking materials could be studied in a controlled environment.

Once performance could be measured, a standard of performance was needed. On a global basis, the International Commission on Illumination suggested a level of 60 mcd/(lux·m^2) as the minimum requirement for retroreflection of pavement marking stripes under wet conditions (*8*). It must be recognized that in measuring performance, a number of devices are being used and developed with varying optics and geometry of both light source and measurement. Inherent in the value of 60 is the acceptance of one device or another as the measuring standard.

Results of laboratory studies measuring wet reflectivity of large beads versus standard beads are shown in Figure 1 for a typical epoxy system and in Figure 2 for a typical thermoplastic system.

As these graphs indicate, the large-bead pavement marking system provides retroreflectivity levels 3 to 4 times higher

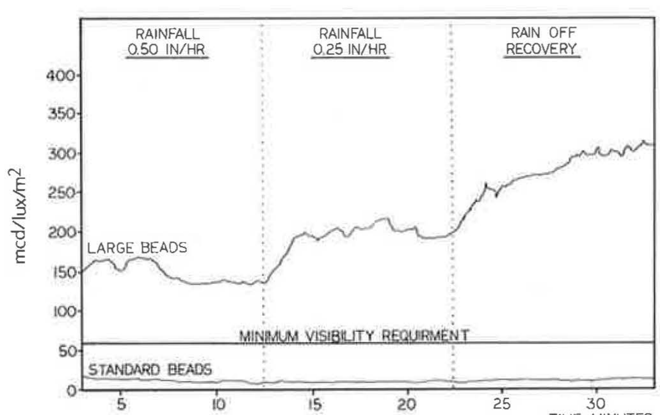

FIGURE 1 Large beads versus standard beads in epoxy.

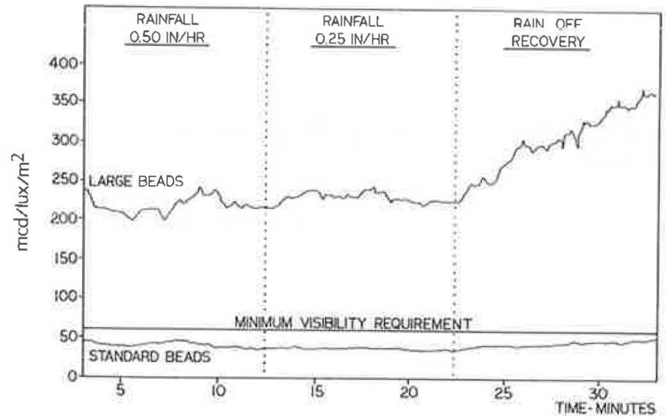

FIGURE 2 Large beads versus standard beads in thermoplastic.

than the minimum visibility requirements in rainfall rates up to ½ in./hr—a level twice the ¼ in./hr considered by meteorologists to be heavy precipitation. When the rain stops, the large-bead pavement markings recover quickly to extremely high retroreflectivity values. A pavement marking line of 350 mcd/(lux·m^2) provides very bright guidance to a driver. By comparison, standard highway beads in the same pavement marking binder fall well below the target of 60 mcd in rainfall. Even more important, after the rain stops, pavement markings with standard beads still do not provide effective visual guidance.

Laboratory studies have shown that as rainfall occurs, a thin film of water spreads uniformly over a stripe containing glass beads. This thin film not only prevents the collection and retroreflection of light, but also changes the optics of the bead by increasing the optical embedment without changing the apparent embedment (Figures 3 and 4).

Further, it was found that when the water film builds, surface tension forces are overcome and gravity causes water to flow down the sides of the beads. Kulakowski and DiGiovanni (*9*) studied this effect and found that the equilibrium water film is about 50 microns (2 mils) deep and that this depth is not strongly influenced by rainfall rate or bead size.

After different bead sizes had been tested, it was determined that properly embedded beads within the size range of 10 to 20 mesh, depending on binder, could overcome the water film effect and reflect light back even in rainfall rates of ½ in./hr. This is because, compared with the optical performance of smaller beads, the performance of large beads is not greatly affected by the same water film. Figure 5 shows relative sizes of large beads versus standard beads.

ROAD TEST SITE

Initial field trials with large beads were conducted in West Milford, N.J. In this rural bedroom community, actual field applications were made with thin-film materials of less than 20 mils (epoxy, polyester), as well as with thick-film materials [thermoplastic, polymethylmethacrylate (PMMA)] in order to optimize bead binder systems. Variations in binder-film thickness, bead size, and bead surface treatments were evaluated for reflectivity, durability, and wet pavement/nighttime performance.

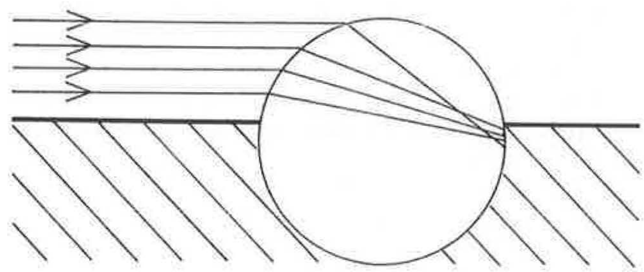

FIGURE 3 Dry bead at optimum 60 percent embedment.

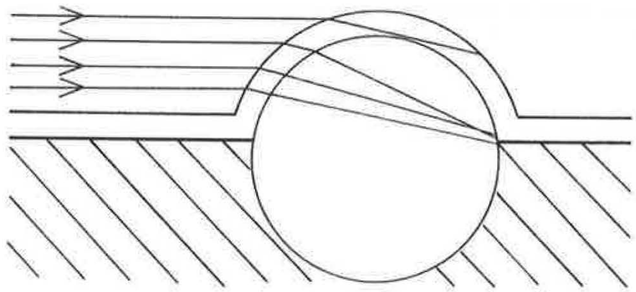

FIGURE 4 Bead with water film preventing retroreflection.

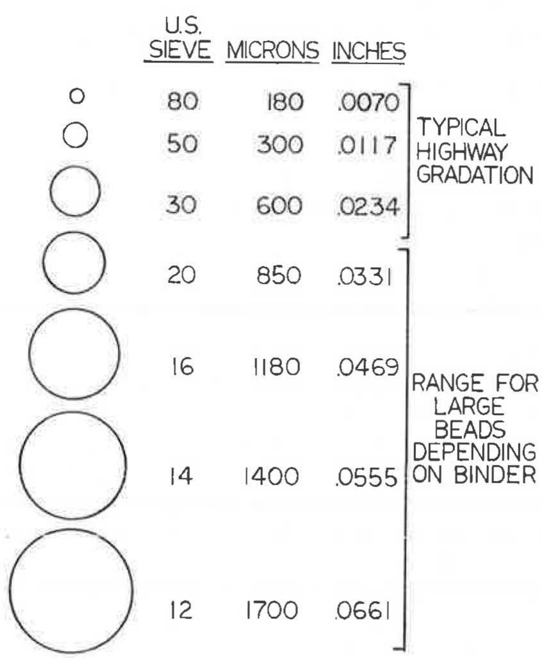

FIGURE 5 Bead size comparison.

Retroreflectivity was measured and documented using portable retroreflectometers as described by the author in 1987 (*10*). Macrophotographs over time at the reflectivity measurement sites were used to correlate bead and binder condition with reflectivity in order to establish durability parameters. Wet pavement/nighttime performance was supported by photographs and videotapes during actual conditions. Rain rates and weather conditions were logged to establish threshold performance parameters. Data generated at this test location, as well as at early state test locations, provided information critical to the development of a wet pavement/nighttime system.

FIELD PERFORMANCE

During the past 3 years, Potters Industries has worked with state and local jurisdictions across the United States to demonstrate the effectiveness of the large-bead system. Demonstrations using existing durable binders have been initiated in 7 geographic areas covering 25 states. Table 1 summarizes field experience with large beads by geography, binder, road type, pavement, and marking application.

Although most tests were applied by contractors, a few were installed by state forces. In all cases technical assistance during installation was supplied by Potters Industries, and timely evaluations were jointly undertaken.

Maryland

One of the earliest test sites was on I-795 northwest of Baltimore. Applied in May 1986, this demonstration was part of a larger contract striping job for epoxy, giving a side-by-side comparison between large beads and standard beads. The installation was evaluated with retroreflectometers at timely intervals with the active cooperation of the Maryland Department of Transportation. Large beads proved to be more retroreflective initially and during subsequent evaluations. In addition, photographic evidence of wet pavement/nighttime reflectivity (see Figure 6), as well as a videotape of wet pavement performance, was obtained 6 months after application in November 1986. Although there was a measurable loss of retroreflectivity due to wear and winter maintenance, macrophotographs show a sufficient amount of large beads still in place after 2 years to provide wet visibility (see Figure 7).

Pennsylvania and Oregon

In November 1986 a contractor-applied epoxy test site was installed on the Schuylkill Expressway, I-76, in Philadelphia. Average daily traffic at this site is in the range of 100,000 vehicles. The installation has performed well through two winters. Wet pavement/nighttime reflectivity was documented on videotape and with photographs (Figure 8). When the test site was last evaluated with state maintenance forces in May 1988 after two winters, a foreman commented that a test area was always evident in the rain. Again, durability was documented with portable retroreflectometers and macrophotographs (Figure 9).

Additional photographic evidence (Figure 10) of wet pavement/nighttime retroreflectivity was obtained from an epoxy test site in Salem, Oregon, 6 months after installation. Water on the pavement from melting snow obliterated all but the large-bead edgeline, which was placed adjacent to a standard edgeline.

Florida and California

Another test site was in Altamonte Springs, Florida, on a two-lane rural road. Installed in March 1987 using spray thermoplastic according to Florida specifications, the site was evaluated by a local observer over a year later and noted as being wet-reflective.

Another thermoplastic demonstration site was in California on a four-lane divided highway. Installed by the California Department of Transportation in August 1987, the site was observed to provide good wet-reflective performance by a state evaluator 6 months after installation.

Ohio

A large-bead polyester system was installed in Ohio in July 1987. This installation was an edgeline at the point where a divided highway becomes a two-lane rural road. Wet-reflective performance was photographed in December 1987 (Figure 11). In the summer of 1988, large-bead/polyester edgelines were installed on the Ohio Turnpike throughout its entire 241-mi length (Figures 12 and 13). Wet pavement/nighttime performance was rated as exceptional.

Figure 14 represents total field experience and evidence of wet pavement/nighttime retroreflectivity.

DISCUSSION OF RESULTS

Whereas visibility in rainfall may only be required for minutes or hours, pavement markings are designed to provide effective guidance for months and years. Service life of the large-bead system is particularly important because final product development to date has been in durable binder materials. In addition to providing effective wet pavement/nighttime visibility, large-bead systems must provide effective dry pavement/nighttime visibility over the life of the line. The International Commission on Illumination has suggested a minimum retroreflectivity level for pavement markings under dry conditions. This level of 150 mcd/(lux·m^2) for white markings is more than twice as high as the 60-mcd level established for wet conditions.

Figure 15 is a compilation of dry-reflective data averaging the relative performance of large beads versus standard beads in epoxy. The data base is from 12 field test sites that include variations in road type, pavement, and line type. The numbers for dry retroreflectivity were obtained using portable Mirolux retroreflectometers. The most recent information shows the curve declining slightly but still above the minimum dry visibility requirement of 150 mcd/(lux·m^2). By comparison, the standard highway beads in epoxy reached the minimum reflectivity level suggested by the International Commission on Illumination within 1 year.

Figures 16 and 17 document the retroreflective performance of large beads in thermoplastic and polyester. Again, the data base is representative of a compilation of test sites and as

TABLE 1 FIELD EXPERIENCE WITH LARGE BEADS

GEOGRAPHY	BINDER	ROAD	PAVEMENT	MARKINGS
Northeast				
Massachusetts	thermo	2 lane	ASP	center
		4 lane		edge & skip
New York	epoxy	Interstate	PCC	edge & skip
Connecticut	epoxy	Interstate	ASP	edge & skip
Middle Atlantic				
New Jersey	epoxy	2 lane rural	ASP	center & edge
	thermo	2 lane rural	ASP	center & edge
	epoxy	Interstate	PCC	edge & skip
Pennsylvania	epoxy	Interstate	ASP	edge & skip
			PCC	edge
Delaware	epoxy	2 lane rural	ASP	center & edge
Maryland	epoxy	Interstate	PCC	edge & skip
	latex paint	Interstate	ASP	edge & skip
Virginia	thermo	4 lane	ASP	edge
Southeast				
North Carolina	epoxy	Interstate	PCC, ASP	edge & skip
Georgia	thermo	4 lane	ASP	edge & skip
Florida	thermo	4 lane rural	ASP	skip
		2 lane	ASP	edge
South Carolina	thermo	4 lane	ASP	edge & skip
Tennessee	polyester	2 lane	ASP	center
Midwest				
Ohio	polyester	Interstate	ASP	edge
		2 lane rural		
Michigan	polyester	2 lane rural	ASP	edge
Wisconsin	polyester	2 lane rural	ASP	center
	epoxy	4 lane	ASP	edge
Illinois	epoxy	2 lane rural	ASP	center
Indiana	thermo/poly	2 lane	ASP	center
Mountain				
Montana	epoxy	Interstate	ASP	edge
Colorado	epoxy	Interstate	PCC	edge
Utah	epoxy	Interstate	PCC, ASP	edge & skip
West				
Washington	epoxy	4 lane urban	ASP	edge & skip
Oregon	epoxy	4 lane	ASP	edge
California	thermo	4 lane	ASP	edge & skip
Southwest				
Texas	thermo	Interstate	ASP	edge & skip

FIGURE 6 Interstate 795, Baltimore, Maryland: large beads in epoxy installed May 1986 on edge and skip; rain of 0.20-in./hr, Nov. 1987.

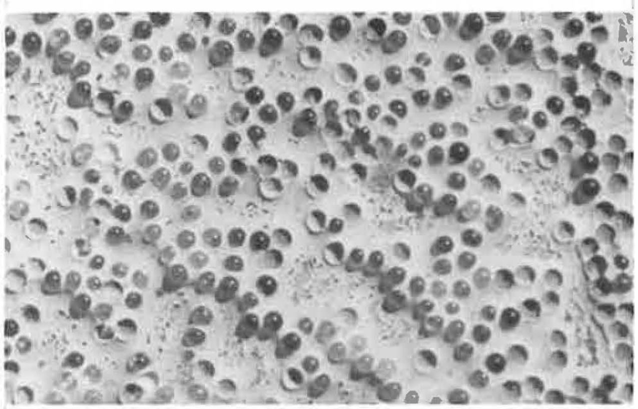

FIGURE 7 I-795 in Baltimore: large beads after 2 years of service.

FIGURE 8 Schuylkill Expressway (I-76), Philadelphia, Pennsylvania: large beads in epoxy installed Dec. 1986; standard beads used for skipline between large-bead skips; Dec. 1986 during recovery after rain.

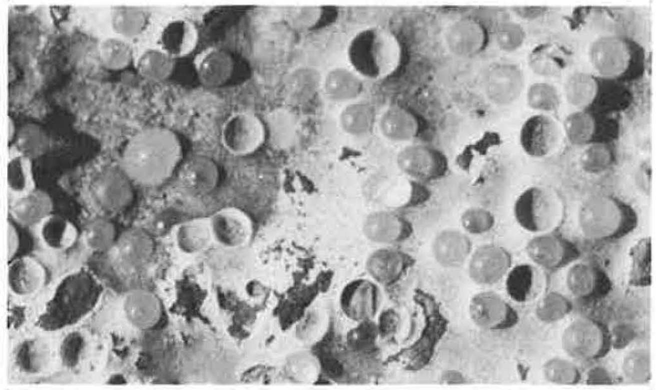

FIGURE 9 Schuylkill Expressway (I-76): large beads after two winters.

FIGURE 10 Salem, Oregon: large beads in epoxy installed June 1987; large bead edgeline adjacent to standard bead line; Dec. 1987, wet pavement/nighttime.

more information is generated, the retroreflectivity curves will be updated. With the thin-film reactive binders, polyester and epoxy, application rates for large beads are the same as those for standard beads. Actual rates are 24 lb/gal for epoxy and 20 lb/gal for polyester. With thicker thermoplastic materials, recommended bead application rates are approximately twice the optimum standard bead application rate because the larger beads do not cover as much area per pound. To date, performance with large beads has been superior to standard bead performance at the same sites.

Potters Industries has extensively demonstrated the effectiveness of large-bead systems since their initial development. In addition to the demonstrations in the United States, large beads are under evaluation in Canada, Europe, Japan, and Australia. Large beads, which Potters has trademarked as Visibeads®, are being actively promoted for use in epoxy, polyester, and thermoplastic. Plans are being implemented to finalize development in traffic paint.

FIGURE 11 **Cleveland, Ohio: large beads in polyester installed Aug. 1987; edgeline with standard beads in background; Dec. 1987, wet pavement/nighttime.**

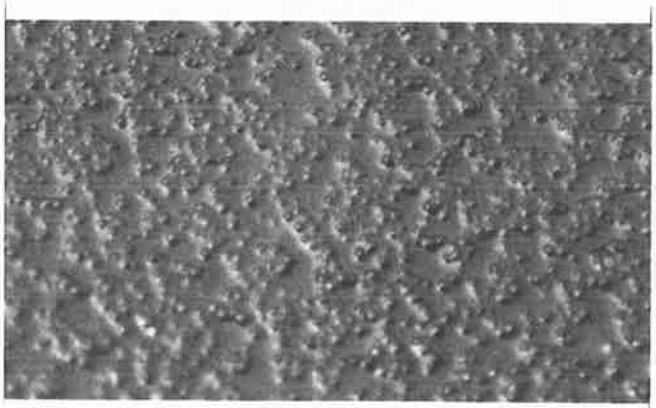

FIGURE 12 **Ohio Turnpike: large beads in polyester (top view).**

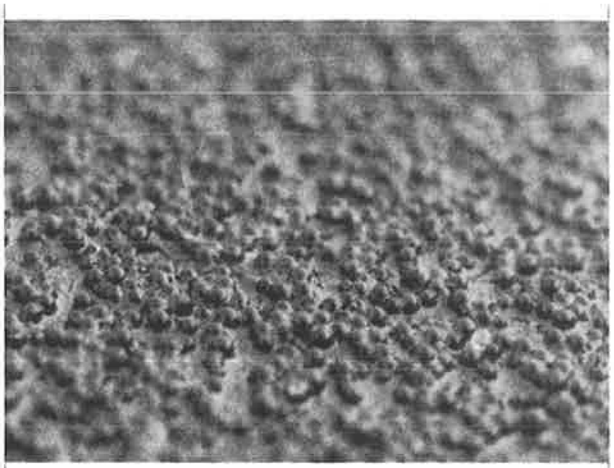

FIGURE 13 **Ohio Turnpike: large beads in polyester (profile view).**

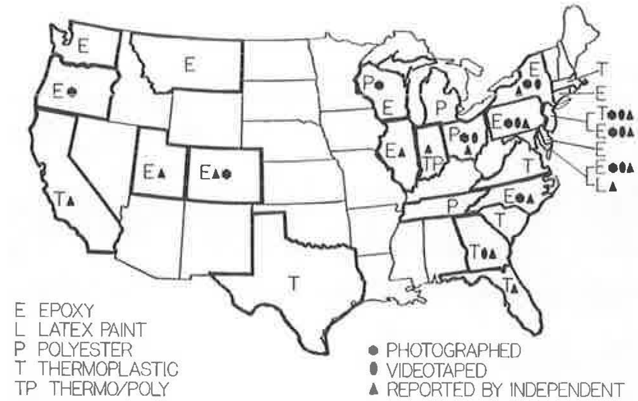

FIGURE 14 **Field experience and wet pavement/nighttime evidence.**

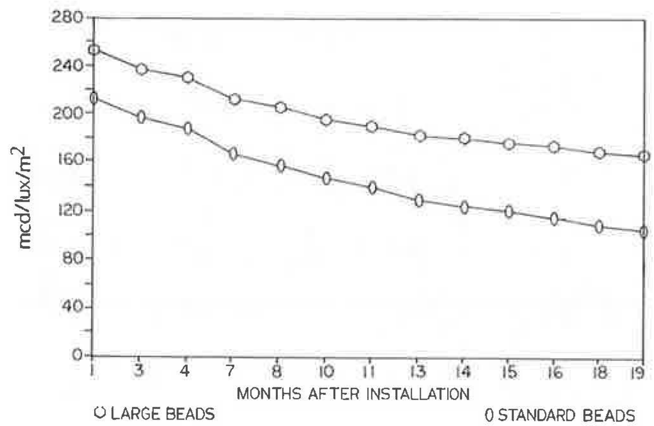

FIGURE 15 **Retroreflectivity: large beads versus standard beads in epoxy.**

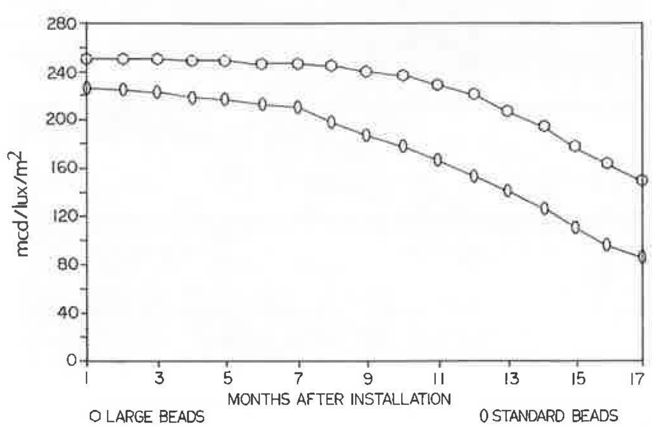

FIGURE 16 **Retroreflectivity: large beads versus standard beads in thermoplastic.**

RECOMMENDED SPECIFICATIONS

Thin-film, chemically reactive binders (polyester, epoxy, and others) have similar liquid properties, and bead size recommendations are dependent on film thickness. Potters Industries has also experimented with a "dual-drop" application system, in which two separate bead drops are used with large beads applied first, immediately followed by a binder-specific standard bead size. Both single- and dual-drop application gives similar initial wet pavement/nighttime performance and dry retroreflectivity. The field trials with the dual-drop system have thus far shown slightly improved dry performance over time as measured by retroreflectometers. Tables 2–4 give the gradation specifications for 100 percent solid, thin-film materials; standard beads for the dual-drop system; and thick-film binders.

CONCLUSIONS

Current gradations of glass beads are correct if selected materials are properly matched and properly applied; however, much more assistance can be provided to road users by treating pavement markings as a system. The term "system" implies design and synergy. Improved roadway performance and service life have been demonstrated at multiple locations in durable materials by properly sizing and treating beads for the thickness and type of binder used. Not only are dry retroreflectivity and durability significantly improved, but delineation of roadways under wet conditions is attained. Work done on NCHRP Project 5-5, started in 1965, suggested the use of large glass beads, but materials were not available at that time to reach the ultimate end product. Now the tools are available to solve these problems.

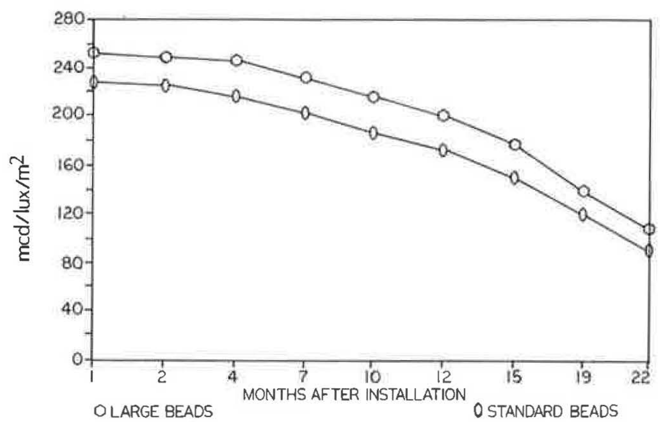

FIGURE 17 Retroreflectivity: large beads versus standard beads in polyester.

TABLE 3 GRADATION OF STANDARD BEADS FOR DUAL-DROP APPLICATION

U.S. Sieve	Percent On
20	0–5
30	5–20
50	30–75
80	9–32
100	0–5
PAN	0–2

TABLE 4 GRADATIONS FOR THICK-FILM BINDERS (THERMOPLASTICS AND PMMA)

U.S. Sieve	Sunbelt	Moderate	Northeast
6	–	–	–
8	0–5	–	–
10	5–20	0–5	–
12	40–80	5–20	0–5
14	10–40	40–80	5–20
16	0–5	10–40	40–80
18	–	0–5	10–40
20	–	–	0–5
PAN	0–2	0–2	0–2

NOTE: Recommended specifications for thermoplastics vary depending on geographic location, with the largest size used in Sunbelt locations. In all cases the dual-drop system is used with thermoplastics.

Application rate: Dual drop—12 lb large + 12 lb std/100 ft². Rounds: 75 percent per screen, 80 percent overall. Coating: binder specific.

TABLE 2 GRADATIONS FOR DURABLE 100 PERCENT SOLID THIN-FILM MATERIALS

15 Mils		15-Mil Dual Drop and 20-Mil Single Drop		20-Mil Dual Drop	
U.S. Sieve	Percent On	U.S. Sieve	Percent On	U.S. Sieve	Percent On
8	–	8	–	8	–
10	–	10	–	10	0–5
12	–	12	0–5	12	5–20
14	0–5	14	5–20	14	40–80
16	5–20	16	40–80	16	10–40
18	40–80	18	10–40	18	0–5
20	10–40	20	0–5	20	–
25	0–5	25	–	25	–
PAN	0–2	PAN	0–2	PAN	0–2

NOTE: Application rate: Single drop—epoxy, 24 lb/gal; polyester, 20 lb/gal. Dual drop—epoxy, 12 lb large + 12 lb std/gal; polyester, 10 lb large + 10 lb std/gal. Rounds: 75 percent per screen, 80 percent overall. Coating: binder specific.

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