Embedment and Retroreflectivity of Drop-On Glass Spheres in Thermoplastic Markings

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Embedment characteristics of drop-on moistureproofed and uncoated glass spheres and their subsequent retroreflectivity were evaluated subjectively in various types of hot-applied thermoplastic traffic markings by illuminating test panels in a dark room. In all of the hot-applied thermoplastic traffic marking types tested, uncoated drop-on spheres were generally overembedded because of positive wetting of the spheres by the thermoplastic traffic marking, and their retroreflectivity varied. The use of moistureproofed drop-on spheres in various thermoplastic traffic marking types resulted in optimal bead embedment with subsequent excellent retroreflectivity. The optimal rate of glass sphere application in all of the thermoplastic marking types was found to be 10 lb of moistureproofed glass spheres per 100 ft²—this rate enhanced retroreflectivity, bead embedment, and coverage. The retroreflectivity of the standard gradation of glass spheres may be enhanced in all of the thermoplastic types by increasing the percentage of spheres retained on U.S. sieves 30, 40, and 50 and by increasing the overall rounds from 70 to 80 percent.

The following is a discussion of the various properties of glass spheres that are needed to define and promote the necessary retroreflectivity for critical nighttime visibility of various thermoplastic traffic marking systems.

Hot-applied thermoplastic traffic markings are 100 percent solid durable markings made initially retroreflective by the simultaneous application of drop-on glass spheres. The control of this glass sphere application is important in providing the maximum amount of initial retroreflectivity and subsequent nighttime visibility.

To ensure the success of drop-on glass sphere applications, the physical characteristics of the thermoplastic system must be considered as well as the physical and chemical characteristics of the glass spheres.

The following tests and observations indicate that the use of moistureproofed glass spheres in various manufacturers' thermoplastic systems helps ensure the optimum bead embedment necessary for maximum retroreflectivity. All cases reveal an average embedment of 60 to 65 percent.

Uncoated glass spheres in various thermoplastic systems become excessively embedded because of positive wetting of the spheres confounded by the resulting envelope of thermoplastic film on the upper periphery of the spheres. Even though the spheres appear to be suspended on the surface, the initial retroreflectivity and subsequent nighttime visibility of the stripe are unacceptable. In some situations, uncoated spheres may be completely embedded in the thermoplastic traffic marking, resulting in no initial retroreflectivity because no spheres are present on the surface at all. The initial retroreflectivity of uncoated spheres in both cases is not effective, and their performance in the various systems is quite unpredictable.

Proper bead rates and uniformity of application are critical factors in promoting and maintaining maximum initial retroreflectivity. Bead application rates should not exceed 10 lb/100 ft². Applications above these rates do not improve the effective retroreflectivity. The uniformity of the glass sphere application also affects the retroreflectivity efficiency and provides the uniform luminance necessary for accurate perception of the delineator.

Better retroreflectivity was obtained with uncoated spheres when higher percentages were retained on U.S. sieves 30, 40, and 60 and also when the existence of overall rounds exceeded 80 percent.

EMBEDMENT OF GLASS SPHERES

Preparation of Test Panels

Illinois uncoated and moistureproofed glass spheres were evaluated in various manufacturers' white and yellow hydrocarbon thermoplastic traffic marking systems by drawing down a 4-in. by 12-in. by .125-in. thermoplastic marking line at 450°F on a black vinyl tile heated to 212°F with a 4- by 4-in. open box doctor blade heated to 450°F. The glass spheres were immediately dropped on the hot stripe through four No. 10 mesh screens to ensure uniform distribution of the spheres over the entire area. The drop-on rate used was 6 lb/100 ft² in all cases. This rate is the minimum application rate generally accepted throughout the thermoplastic marking industry. The different thermoplastic systems are differentiated as A, B, C, and D. White and yellow samples were tested from each system.

Evaluation Method

All bead applications were evaluated subjectively in a dark room illuminated by a small flashlight at distances of 10 to 25 ft. Photomicrographs were taken of the various applications perpendicularly and in cross section to show bead distribution and embedment characteristics. Bead embedment

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TABLE 1 SUBJECTIVE EVALUATION OF RETROREFLECTIVITY AND GLASS SPHERE EMBEDMENT

WHITE SYSTEMS

(RETROREFLECTIVITY/EMBEDMENT)

System	Sphere 1 Uncoated	Sphere 2 Uncoated	Sphere 2C Moisture Proofed
A	Minimal/95-100	Moderate/80-85	Excellent/60-65
B	Minimal/95-100	Moderate/80-85	Excellent/60-65
C	Moderate/80-85	Moderate-Excellent/70-75	Excellent/60-65
D	Minimal/95-100	Minimal 95/100	Excellent/60-65

YELLOW SYSTEMS

(RETROREFLECTIVITY/EMBEDMENT)

System	Sphere 1 Uncoated	Sphere 2 Uncoated	Sphere 2C Moisture Proofed
A	Minimal/95-100	Moderate/80-85	Excellent/60-65
B	Minimal/95-100	Moderate/80-85	Excellent/60-65
C	Minimal-Moderate/90-95	Moderate/80-85	Excellent/60-65
D	None/100	None/100	Excellent/60-65

TABLE 2 SUBJECTIVE EVALUATION OF COVERAGE, RETROREFLECTIVITY, GLASS SPHERE EMBEDMENT, AND VISUAL ACUITY AS RELATED TO APPLICATION RATES

Application Rates (*) (Lbs./100 ft.^{2})	Coverage	Retro-Reflectivity	Glass Sphere Embedment	Visual Acuity
2	Minimal	Min-Mod	60 - 65	Dull
4	Minimal	Moderate	60 - 65	Dull
6	Moderate	Excellent	60 - 65	Sharp
8	Excellent	Excellent	60 - 65	Sharp
10	Excellent	Excellent	60 - 65	Sharp
12	Excessive	Excellent	50 - 55	Scattered
14	Excessive	Excellent	40 - 45	Scattered

* (Spheres 2C) Moisture Proofed

was subjectively estimated and described visually using cross-sectional photomicrographs. Tables 1 and 2 evaluate coverage, retroreflectivity, and glass sphere embedment.

Mechanisms and Influencing Embedment

It should be noted at this point that surface tension plays an important role in controlling bead embedment in the various thermoplastic systems tested. There is minimum shrinkage of the thermoplastic film compared with most traffic paint systems; thus the effect of various coatings on glass spheres in traffic paint is not wholly applicable to thermoplastic traffic marking systems that are 100 percent solid systems. The film thicknesses involved are six times that of most dried paint films, therefore necessitating greater control by the use of treated spheres.

Uncoated Glass Spheres

Drawdowns made with uncoated spheres in various thermoplastic systems indicate excessive bead embedment by either positive wetting or total embedment, or both. Positive wetting reveals variable embedment of 75 to 95 percent, with another 5 percent interference by the thin thermoplastic envelope characteristically formed around the periphery of the untreated spheres (Systems A, B, and C). Total embedment is encountered in System D. This overembedment results in unacceptable retroreflectivity in all systems (A, B, C, and D). Figures 1–6 illustrate drawdowns, cross sections, and embedment of Spheres 1 and 2. See Tables 3 and 4 also.

Moistureproofed Glass Spheres

Use of coated (moistureproofed) spheres results in optimum embedment of 60 to 65 percent in all thermoplastic systems (A–D). The initial retroreflective properties were excellent (see Figures 7 and 8). These spheres are denoted 2C (see Figure 9). As stated earlier, optimum bead embedment is critical in providing maximum initial retroreflectivity. It is also important in providing the necessary retention of glass spheres to maintain a reasonable level of retroreflectivity until the thermoplastic wears down to expose intermix glass spheres (see Table 5).

Controlled Wear and Retroreflectivity

Drop-on glass spheres eventually wear off. Controlled wear is important in durable markings to promote continual renewal

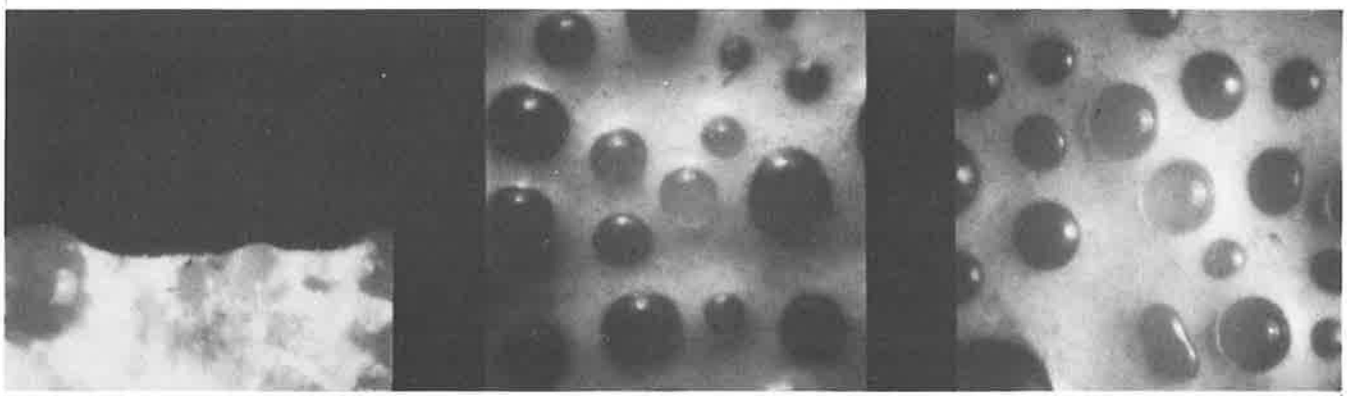

FIGURE 1 Drawdowns and cross section of Systems A, B, and C (bead rate: 6 lb/100 ft^2, white). *Left*, Sphere 1, cross section (magnified 100×). *Middle*, Sphere 1, top view (magnified 100×). *Right*, Sphere 2, top view (magnified 100×).

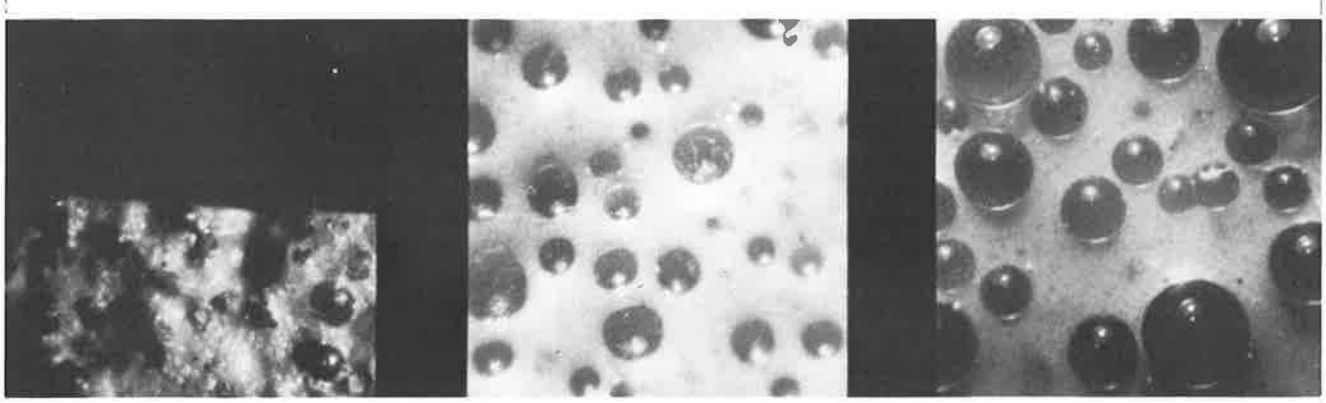

FIGURE 2 Drawdowns and cross section of Systems A, B, and C (bead rate: 6 lb/100 ft^2, yellow). *Left*, Sphere 1, cross section (magnified 100×). *Middle*, Sphere 1, top view (magnified 100×). *Right*, Sphere 2, top view (magnified 100×).

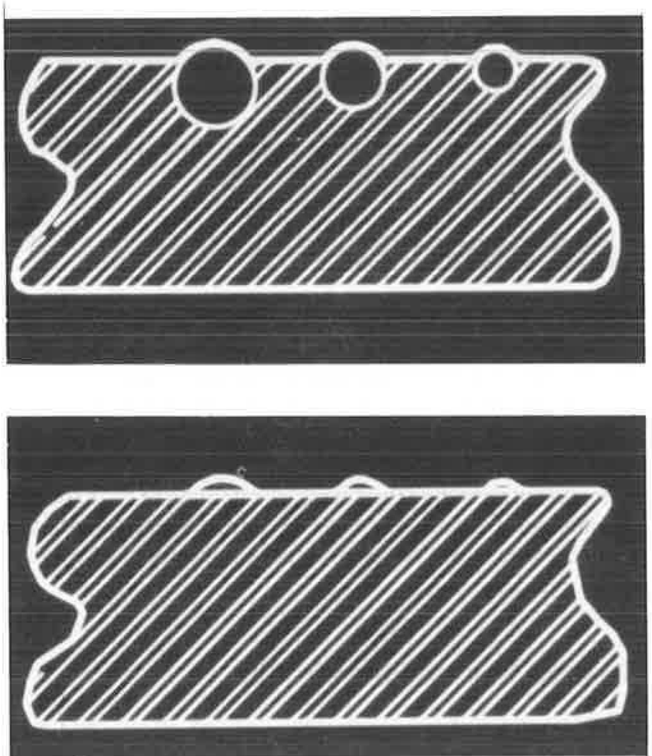

FIGURE 3 Systems A, B, and C, Spheres 1 and 2 (80 to 95 percent embedment).

of the surface. The cleaning and brightening of the surface of the thermoplastic by exposing intermix glass spheres is paramount to continued retroreflectivity and subsequent nighttime visibility.

APPLICATION RATES AND UNIFORMITY

Influence of Substrate and Material Temperatures

Drawdowns were made at substrate and material temperatures of 212°F and 450°F, respectively. The evaluations were made at the higher temperature extremes as worst-case situations. The above substrate and material temperatures exceed maximum temperatures found in any actual field situation.

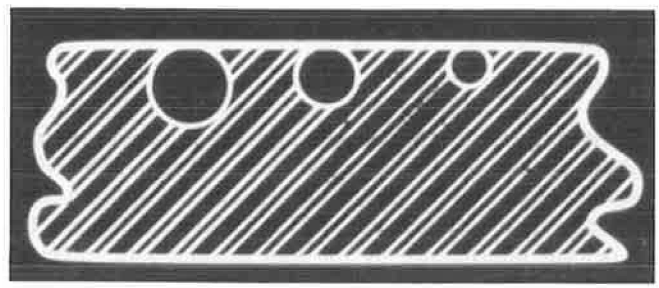

FIGURE 6 System D, Spheres 1 and 2 (total embedment).

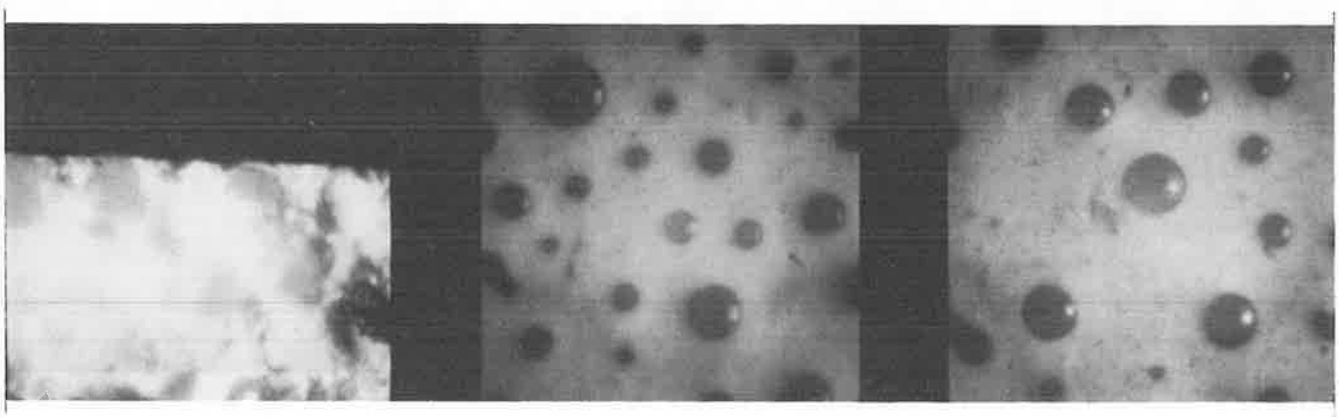

FIGURE 4 Drawdowns and cross section of System D (bead rate: 6 lb/100 ft^2, white). *Left*, Sphere 1, cross section (magnified 100×). *Middle*, Sphere 1, top view (magnified 100×). *Right*, Sphere 2, top view (magnified 100×).

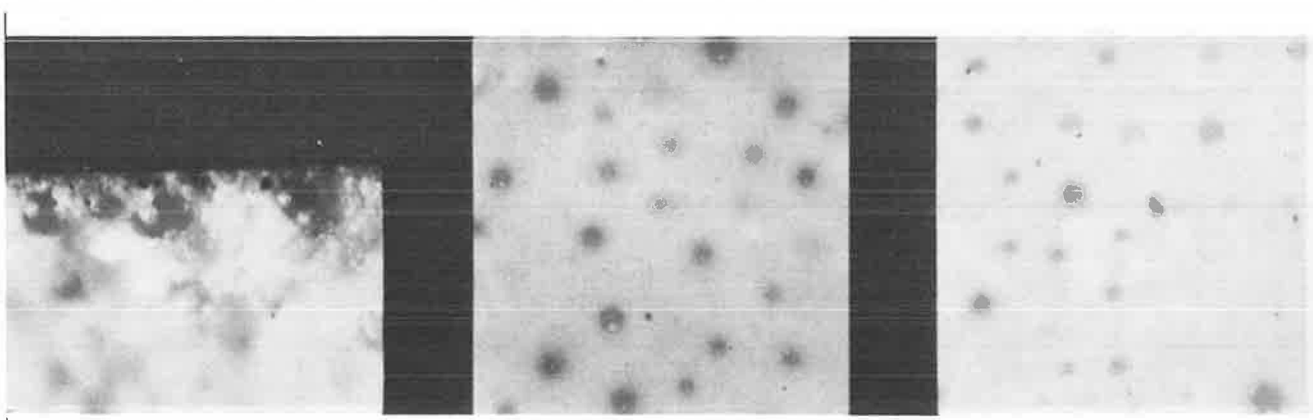

FIGURE 5 Drawdowns and cross section of System D (bead rate: 6 lb/100 ft^2, yellow). *Left*, Sphere 1, cross section (magnified 100×). *Middle*, Sphere 1, top view (magnified 100×). *Right*, Sphere 2, top view (magnified 100×).

TABLE 3 SIEVE ANALYSIS OF UNCOATED ILLINOIS GLASS SPHERES (TYPE 1)

US Sieve	% Retained	% Passing	Spec. % Passing
# 20	0.01	99.99	100
# 30	0.09	99.90	75/100
# 40	2.56	97.34	
# 50	64.36	32.98	15/40
# 60	10.36	22.62	
# 70	15.20	7.42	
# 80	3.43	3.99	
#100	3.75	0.24	0/10
#200	0.24	0.00	0/2
PAN	0.00		

% Rounds - 70 overall

TABLE 4 SIEVE ANALYSIS OF UNCOATED ILLINOIS GLASS SPHERES (TYPE 2)

US Sieve	% Retained	% Passing	Spec. % Passing
# 20	0.00	100.00	100
# 30	1.02	98.98	75/100
# 40	13.77	85.21	
# 50	50.58	34.63	15/40
# 60	18.80	15.83	
# 70	13.31	2.52	
# 80	1.21	1.31	
#100	1.11	0.20	0/10
#200	0.19	0.01	0/2
PAN	0.01		

% Rounds - 83 Overall

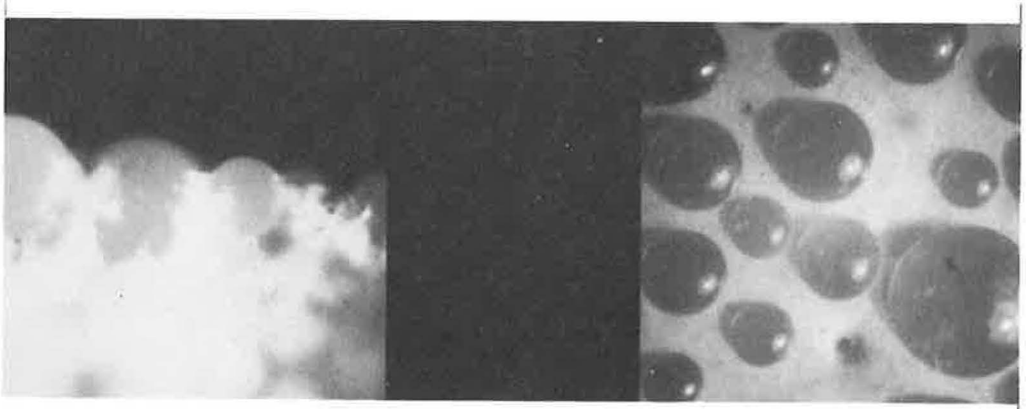

FIGURE 7 Drawdowns and cross section of Systems A, B, C, and D, Sphere 2C (bead rate: 6 lb/100 ft^2, white). *Left*, cross section (magnified 100×). *Right*, top view (magnified 100×).

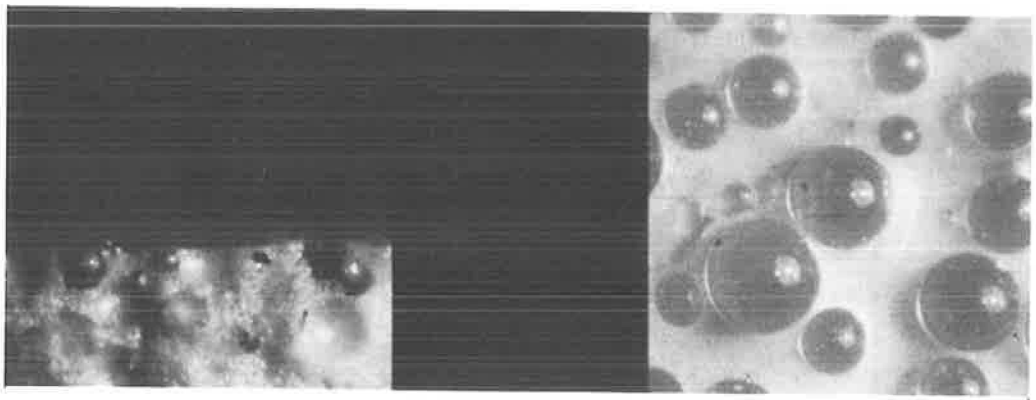

FIGURE 8 Drawdowns and cross section of Systems A, B, C, and D, Sphere 2C (bead rate: 6 lb/100 ft^2, yellow). *Left*, cross section (magnified 100×). *Right*, top view (magnified 100×).

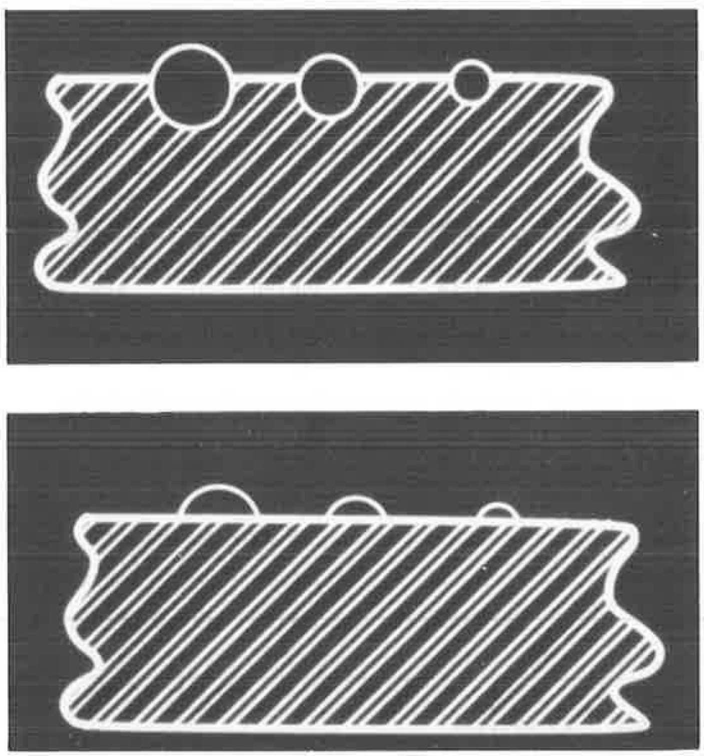

FIGURE 9 Systems A, B, C, and D, Sphere 2C (65 percent embedment).

TABLE 5 SIEVE ANALYSIS OF MOISTUREPROOFED ILLINOIS GLASS SPHERES (TYPE 2C)

US Sieve	%Retained	%Passing	Spec. %Passing
# 20	0.00	99.98	100
# 30	10.16	89.82	75/100
# 50	71.82	18.00	15/40
#100	17.75	0.25	0/10
#200	0.25	0.00	0/2
PAN	0.00		

Influence of Application Rates

The application rate of drop-on spheres also affects the retroreflectivity of the thermoplastic system. By using the same drawdown procedure as described initially, bead drop-on rates of 2, 4, 6, 8, 10, 12, and 14 lb/100 ft^2 were evaluated for visual luminance in System D using moistureproofed spheres 2C. As previously described, use of moistureproofed spheres results in optimum embedment in all thermoplastic systems.

The 2- and 4-lb/100 ft^2 rates were minimally retroreflective and unacceptable due to poor coverage (see Figures 10 and 11). The 6-, 8-, and 10-lb/100 ft^2 applications were all bright and well defined. The 6-lb/100 ft^2 application revealed minimal acceptable brightness as compared with the higher application rates (Figure 12). The 8-lb/100 ft^2 application (Figure 13) was bright and well defined but the coverage was not as uniform as that at 10 lb/100 ft^2 (Figure 14).

When the application rate exceeded 10 lb/100 ft^2, the beads began to overlap (see Figures 15 and 16). Bead embedment diminished, as is evident by the raised appearance of the spheres. It is evident that the spheres were competing for thermoplastic film. Excessive application rates resulted in minimally embedded glass spheres and insufficient retroreflectivity for accurate visual color and delineation perception. The 10-lb/100 ft^2 application was not only bright and well defined but also optimal in coverage. Thus, the optimum application rate is 10 lb/100 ft^2 (see Table 2).

Influence of Uniformity on Glass Sphere Retroreflectivity

Uniformity is important in maintaining uniform luminance necessary for visual perception and acuity of the delineator (stripe). Ten pounds of moistureproofed glass spheres evenly distributed over an area of 100 ft^2 will produce the uniform luminance necessary for accurate perception of the delineator. As previously discussed, glass sphere applications below 10 lb/100 ft^2 do not adequately cover the unit area and result in loss of maximum luminance and visual acuity. In this study, this was accomplished by using a 3½ in. inside-diameter cylinder with four No. 10 mesh screens inserted 1½ in. apart (see Table 2).

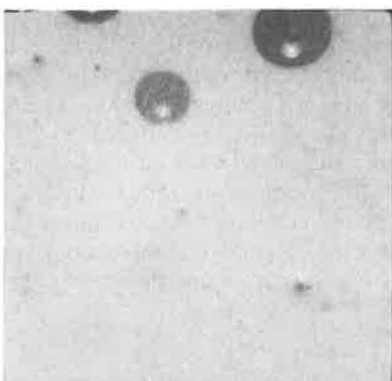

FIGURE 10 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 2 lb/100 ft^2, yellow).

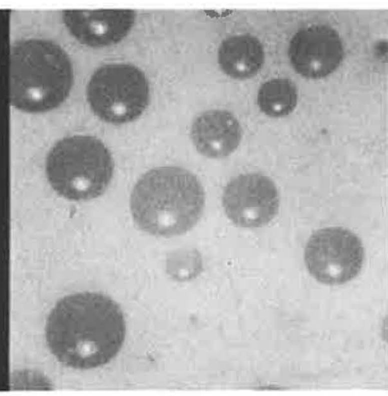

FIGURE 11 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 4 lb/100 ft^2, yellow).

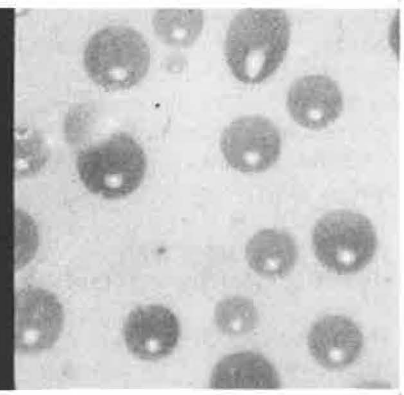

FIGURE 12 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 6 lb/100 ft^2, yellow).

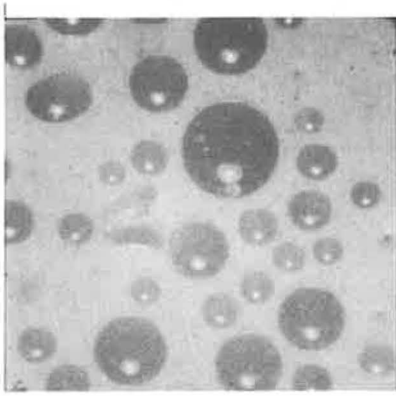

FIGURE 13 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 8 lb/100 ft^2, yellow).

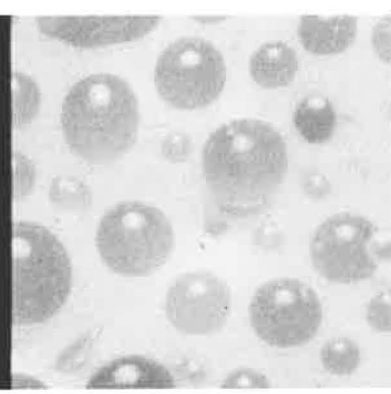

FIGURE 14 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 10 lb/100 ft^2, yellow).

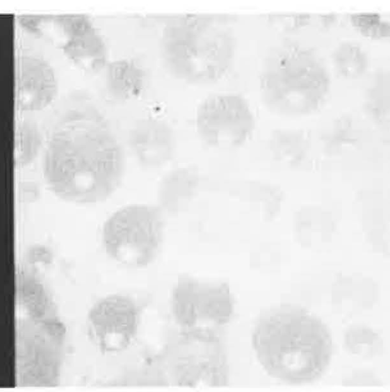

FIGURE 15 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 12 lb/100 ft^2, yellow).

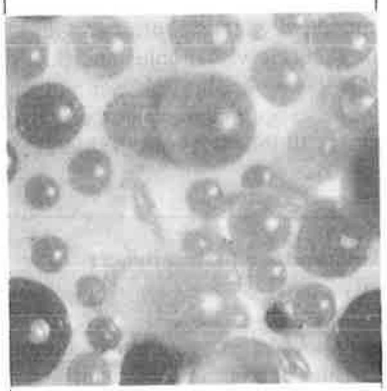

FIGURE 16 Glass sphere drop-on rates, System D, Sphere 2C (bead rate: 14 lb/100 ft^2, yellow).

GRADATIONAL ANALYSIS

Uncoated Glass Spheres (Types 1 and 2)

Finally, an analysis was made of two manufacturers' uncoated spheres that meet Illinois specifications for drop-on glass spheres. Since some differences in the retroreflectivity or brightness resulted in the use of these spheres, it was thought that the brighter panels had some larger spheres. The sieve analysis revealed a higher percentage of +40 and +60 spheres for sphere 2. Also, the overall roundness was 70 percent for sphere 1 and 83 percent for sphere 2 (see Tables 3 and 4) (*1*). While this accounted for some slight differences in brightness, neither sphere produced acceptable retroreflectivity.

Moistureproofed Spheres (Type 2C)

The analysis of the moistureproofed spheres (2C) reveals a larger percentage of 30- and 50-mesh glass spheres than the uncoated spheres. It is hypothesized that larger spheres would aid the initial retroreflectivity of the system by increasing the brightness as it did with uncoated spheres. Further study will be done to confirm this hypothesis (see Table 5).

RECOMMENDATIONS

Moistureproofed Spheres

Based upon the above results, moistureproofed spheres are recommended for all existing thermoplastic traffic marking systems to date. Many states presently specify the use of moistureproofed spheres in their systems.

Specifications

To be properly controlled, the use of moistureproofed spheres should be specified by the state. ASTM and AASHTO standards define tests that can be easily performed in the laboratory to test for moistureproofing (*2*). No significant cost increase is incurred with the use of these spheres, which are produced by all bead manufacturers.

In order for a material to bend or refract light, it must be transparent and spherical. This also applies to glass spheres (*3*). Optimum bead embedment for 1.50 refractive index spheres is 60 percent (*4*). At 75 percent embedment, retroreflectivity qualities and subsequently luminance qualities diminish rapidly. Likewise at 50 percent embedment or less, retroreflectivity is diminished and amplified by the early removal of glass spheres. Further study will evaluate retroreflectivity as a function of glass sphere gradation and roundness.

Quality Control

None of the above specifications are totally helpful if proper control is not used. Application of glass spheres must be monitored to ensure good application techniques. Moistureproofed spheres provide uniform optimum embedment and retroreflectivity. This provides application uniformity.

It is hoped that the above tests and observations will help in the understanding of the mechanisms influencing good retroreflectivity and nighttime visibility. Test procedures and apparatus are detailed for use in evaluating the various systems and are available from the author upon request.

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