away easily. This plastic type of volcanic ash has been described in a previous paper (*6*)

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A STUDY OF GLASS BEADS FOR REFLECTORIZING TRAFFIC PAINT

V H. Lyon, *Laboratory Director* and D. L. Robinson, *Senior Materials Engineer*, *Missouri State Highway Department*

SYNOPSIS

Glass beads provide the best currently known means of improving the night visibility of painted stripes because of their optical properties which cause the light rays of headlights to be returned to the driver by reflex-reflection, thus providing a paint stripe with positive and striking visibility In addition, the color of the binder is maintained

Because of the differences in the physical and chemical properties of available glass beads, the Missouri State Highway Department undertook a study to obtain technical information upon which an evaluation of the available products could be based, and from which a specification could be designed that would include those products which showed satisfactory performance Eight different glass beads obtained from four manufacturers were studied The beads were graded from the No 20 to the No. 100 sieve Following the standard striping procedure used in Missouri, all beads were applied by gravity on the surface of the freshly applied paint This procedure provides immediate reflectance and the grading of the beads promotes maintenance of reflection since the diminishing sizes become exposed as the binder wears away Standard Missouri Specification yellow traffic paint was used for the binder

Laboratory tests for chemical composition and physical characteristics including gradation, index of refraction, structural stability, solubility in acid, and freezing effects, were made A laboratory method for preparing beaded paints, and several pieces of apparatus developed during the investigation are described Field tests included accelerated (transverse) and unaccelerated (longitudinal) installations Periodic reflectance measurements of the field stripes were made with the Hunter night-visibility meter and, in addition, the stripes were examined under a 20× glass to determine bead damage and loss Visual observations were made and found to be in agreement with the Hunter meter. A photographic method for the purpose of maintaining a permanent record of the visual appearance of the stripes at night is described.

Four of the beads studied were composed of glasses having a low silica content. One type was non-resistant to moisture and showed rapid deterioration of reflectance Other types with low silica but with certain additional metallic oxides seemed to be improved in maintaining reflectance. The other four beads were composed of silica-soda-lime glasses of normal (high) silica content One of these was more coarsely graded and was structurally weak because of numerous bubbles and it deteriorated in reflectance at a more rapid rate than the other normal silica glasses because of breakage and loss under traffic wear. Another had poor initial reflectance, owing to surface scoring and scratching and milkiness Of the eight beads studied, two composed of glass of normal silica were considered to have performed satisfactorily and two with low silica content gave promise of giving satisfactory results. The low silica glasses had consistently higher indexes of refraction than the normal types and gave higher initial reflectance values

This is essentially a progress report and many of the features of the study were of an exploratory nature Some indications and conclusions are given and some suggestions are made regarding desirable additional studies.

As increased highway facilities have been provided through the past several decades, the volume of traffic has increased greatly, with proportionate increase in hazards The use of paint lines to indicate the location of directional traffic lanes, and later to indicate zones unsafe for passing, has been developed through necessity and is now an essential feature of traffic control. Both the color of the traffic line and its location are used to indicate the safe directional driving procedure, and efforts are being made to establish uniform standards for marking procedure Color and brightness contrasts seem to function very well for daytime use but are much less effective at night, particularly in the case of fast moving traffic. Paint traffic lines are short-lived under the heavy wear of high volume traffic and improvement in composition to resist wear may tend to produce surface conditions which give reduced visibility under incident light beams from headlights.

In order to improve the night visibility of such lines, efforts were made to increase reflectivity by introducing into the paint film inert particles which would produce a rough surface. Later, light colored stone chips were added to the wet surface and glass fragments were tried. Finally it was realized that the increase in reflectance from roughness (diffuse reflection) was not the desired solution but that the light rays from the vehicle headlights should be conserved rather than diffused and should be returned to the driver by reflex reflection Glass beads have the desired reflex or directional reflecting properties when properly located in an opaque film such as paint provides. The paint films complete the mirror effect and bring into play the optical properties of the glass of which the bead is composed. Trials of beads proved successful both as surface applications on the wet paint film and premixed with the paint before application, the latter procedure generally requiring longer traffic wear to free the upper parts of the beads from paint coating so that maximum reflectance could be obtained.

Early use of reflectorizing beads was limited but increased rapidly as trials demonstrated the great improvement in night visibility of the traffic lines. As is often the case with new materials, early use was not based on specifications. As patent restrictions were eliminated, sources of production increased and it was found that physical characteristics of raw materials and of the manufactured products varied greatly. Early attempts at specifications for beads were in very general terms since little information was available on the factors which affected the service characteristics of the product. Glass is a complicated material which does not always yield easily to analysis and about which even the experts seem to lack information in this new and radically different field or type of use. The technology of glass and its manufacture, however, has been covered in the literature (*1*), (*2*).[1]

[1] Italicized figures in parentheses refer to the list of references at the end of the paper.

Experimental installations by the Missouri Highway Department proved to be so popular and so advantageous to traffic that, following the recent war, an attempt was made to reflectorize all passing control traffic lines. Since the price of reflectorizing beads varies through a rather wide range and the amount of material to be used increased tremendously, it became imperative that technical information be obtained upon which evaluation of the several available products could be based and by means of which purchase specifications could be designed. Work to these ends has been underway for about 1 yr. and interest in the results has been so widespread that it seems highly desirable that our work to date be reported.

Since the most urgent need was for information regarding the reflectorizing material itself and since experience with the use of the paint composing the carrying film or binder seemed to be fairly satisfactory, the first studies have been made, using regular traffic paint with the only intended variable material being the reflectorizing beads. No specific studies were made of premixed paint and beads because use of this material was not contemplated. Previous experience had indicated that such materials could not be satisfactorily dispensed through the type of equipment used and also that there was a slow development of reflectivity with premixed materials.

The plan of attack may be outlined as follows:

1. Laboratory studies of the chemical and physical characteristics of the beads.
   a. Chemical analysis
   b. Solubility in various agents
   c. Structural stability
   d. Index of refraction
   e. Gradation
   f. Freezing and thawing effects
   g Atmospheric exposure of beaded panels
2. Accelerated traffic tests by means of transverse pavement stripes.
   a. Visual observations
   b. Directional reflectance measurements
   c Photographic ratings
3. Traffic tests under unaccelerated service conditions.
   a. Visual observations
   b. Directional reflectance measurements

The laboratory studies were for the purpose of establishing the original characteristics of the materials to serve as background information for the later studies. Accelerated transverse tests were selected because this approach had proved highly satisfactory in the development of standard specifications for the regular unreflectorized traffic paints and thus seemed to be the most logical and promising method for evaluating and predicting the service of the same general material modified by the addition of the reflectorizing beads. The unaccelerated traffic tests were used to check the validity of the accelerated transverse tests. The longer test sections and the longer duration of observational time were thus intended as checks upon the more rapid and convenient accelerated tests and for the purpose of obtaining additional information which tests involving less of the time element might not produce. Since the unaccelerated traffic test installations were located on continuous stretches of 2- and 4-lane pavements with rather high rates of traffic, limited random observations at other locations were made in order to assure that the traffic variable did not overshadow or invalidate the trends shown by other service tests.

Eight different glass beads, obtained from four manufacturers, were studied and, are coded alphabetically A through H. Beads, identified as A to E, inclusive, were available at the beginning of the investigation and F was submitted shortly thereafter. Bead F was similar in composition to Bead A except for the absence of bubbles and seeds and was reported as representing only a laboratory nonproduction batch. Bead G was submitted rather late in the investigation and Bead H was received only shortly before the preparation of this report. So far as is known currently, only beads C, D,E and H are in production and the manufacturer of Bead H has indicated some likelihood of an early change in its formulation. Each bead submitted was studied, however, to gain information regarding its characteristics and durability, since each differed from the others in some respect.

The chemical analyses of the beads are shown in Table 1 and the physical properties in Tables 2, 3 and 4. Following is a general description of the beads used in the investigation:

Bead A—A graded glass bead having a yellow cast in the bulk, the individual particles having numerous bubbles and seeds with some pits on the bead surfaces extending well into the bodies of the beads In addition there appear to be planes of weakness forming incipient pits. The non-spherical particles, approximating 8 percent of the total, consist of fused spheroids, ovates, dumbbells, elongated fused glass with a few discs and angular pieces

Bead B—A graded glass bead of dull appearance Many of the particles are milky or surface scored and semi-opaque and contain numerous bubbles. Approximately 5 percent of the particles are non-spherical consisting mainly of fused spheroids, ovates and elongated pieces

Bead C—A graded glass bead of very clear and transparent glass free of bubbles The gradation of this bead is somewhat finer than others used in the investigation and the coarser particles are less spherical being somewhat irregular in shape with firepolished edges The non-spherical content approximates 13 percent.

Bead D—A graded glass bead only slightly less clear than Bead C, some particles of which contain small bubbles and seeds The non-spherical content approximates 10.0 percent and consists principally of fused spheroids, ovates and elongated particles

Bead E—A graded glass bead having numerous bubbles and seeds in practically all of the individual particles The gradation of this bead is considerably coarser than the others used in the investigation. The non-spherical content approximates 14 0 percent and consists of fused spheroids, ovates and elongated particles

Bead F—A graded glass bead which is very similar to A except that it contains no bubbles or seeds

Bead G—A graded glass bead having a yellow cast in the bulk. The beads contain numerous bubbles and seeds with an appreciable quantity of elongated fused particles, dumbbells and ovates with a quantity of rather long angular particles The non-spherical content approximates 8 0 percent.

Bead H—A graded glass bead having a golden cast Most of the particles have small bubbles and there are numerous surface planes of weakness forming incipient pits The non-spherical content approximates 7.0 percent and consists of fused spheroids, ovates and elongated particles.

The unaccelerated test sections, which are more fully described later, were located on the 4-lane pavement on Route US 66, St. Louis County, extending 10 miles west of the St Louis city limits and on 2-lane pavements on Routes P, St Louis County, at the intersection of Heege Road; US 40, Callaway and Montgomery Counties, east of Kingdom City; and US 50, Pettis and Johnson Counties, Sedalia to Warrensburg Beads A through E were used on Route US 66, A through F on

TABLE 1
CHEMICAL ANALYSES OF GLASS BEADS

	Bead							
	A	B	C	D	E	F	G	H
	%	%	%	%	%	%	%	%
SiO_2	26 28	71 28	71 30	68 00	71 28	26 66	25 66	26 66
B_2O_3	3 92	0 00				3 65	1 44	7 18
Al_2O_3	9 38	0 51	1 31	0 75	0 76	9 96	8 10	16 33
Fe_2O_3	0 40	0 24	0 18	0 34	0 16	0 40	0 36	0 16
P_2O_5	0 01					0 01	3 88	0 07
BaO	0 16		0 03	2 41		0 16	0 00	0 00
CaO	34 06	10 61	6 44	9 06	10 93	33 40	26 54	15 34
MgO	11 95	3 03	3 76	2 54	1 95	12 42	13 98	13 92
Na_2O	10 07	13 20	16 52	14 79	13 58	10 20	10 11	4 17
K_2O	0 10	0 30	0 39	0 68	0 30	0 00	0 02	0 13
TiO_2							4 68	15 22
ZrO_2							2 54	0 42
ZnO							1 64	0 00
SO_3		0.45			0 53			
PbO				1 40				
MnO				0 06				
F	6 07					5 37	1 62	0 00
Oxygen equivalent of Fluorine	−2 56					−2 26	−0 91	
Total	99 84	99 62	99 93	100 03	99 49	99 97	99 66	99 60

Route P; C, D and G on Route US 40; and C, D, E and G on Route US 50. Since "no passing" stripes are the ones commonly reflectorized in Missouri, the beads were applied on yellow paint. On the 4-lane pavement the beaded stripes were placed adjacent to and on both sides of the centerline. On the 2-lane pavements the beaded stripes were placed in the center of the traffic lanes, in accordance with standard Missouri practice. The accelerated transverse line test section, on which all of the beads were applied, was located on Route US 50, Cole County, at the western edge of Jefferson City.

Beads B, C, D and E, all having a high silica content, yielded nicely to chemical analysis following the procedures outlined in ASTM Method C 169 – 43 and reproducible results were obtained. Beads A, F, G and H with low silica contents could not be satisfactorily analyzed by these procedures, evidently because of unusual composition and it was necessary to use other procedures to obtain the oxide analysis (*3*), (*4*), (*5*), (*6*), (*7*). In making the chemical analyses it was noted that Beads A, F, G and H were decomposed by hot 1:1 H_2SO_4 solution. Beads A, F and G were also decomposed by cold 1:1 H_2SO_4 solution while H was attacked and etched on the surfaces but not decomposed. The hot acid solution was more severe and Beads A, F, G and H were attacked by hot solutions of the order of 1 part acid to 50 parts water. Beads B, C, D and E were not affected by either the hot or cold acid solution. Based on acid resistance Beads A, F and G were the least chemically durable followed by H with Beads B, C, D and E showing no effect in contact with the acid solutions. Beads A, C and D were boiled for 30 min. in a concentrated NaOH solution. At the end of this period Beads C and D were slightly coated but a much heavier coating was noted on Bead A indicating less resistance to the alkali.

A freezing and thawing test of Beads A, C and D was conducted by freezing in water at 0 F. and thawing in water at room temperature. At the end of 10 cycles the gradations of the beads were checked but no degradation had occurred. However, it was noted that Bead A was dulled and had been definitely affected on the surface. Examination under 20× glass showed white deposits on this bead, a condition which was later noted on some of the beads after application in the paint film. Immersion and drying tests of the A bead produced the same effect and qualitative tests of the water in which the beads had been immersed showed the presence of aluminum, calcium and boron. Bead F was similarly affected by water immersion. None of the other beads examined showed this effect.

The indexes of refraction of the glasses composing the beads were obtained by the liquid immersion method and are reported in Table 2.

TABLE 2
INDEX OF REFRACTION OF GLASS BEADS, LIQUID IMMERSION METHOD AT 25 C.

Bead							
A	B	C	D	E	F	G	H
1.594	1.527	1.513	1.523	1.528	1.602	1.587	1.587

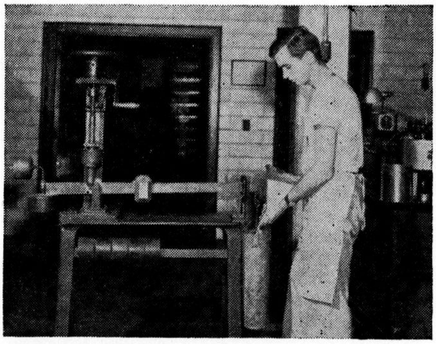

Figure 1. Apparatus for Determining Crushing Strength of Glass Beads

Because some of the beads contain bubbles and seeds in varying degrees, it was thought that a crushing strength test would yield information of value in connection with the useful life of the bead under traffic impact and wear. An apparatus was designed for this purpose by slightly modifying a Riehle cementation briquette-making machine as shown in Figure 1. The cylinder die and table of the machine were removed and the counter balance replaced with a metal bucket $4\frac{1}{2}$ in. in diameter by 16 in. in length. A small hard steel plate placed under the plunger serves to hold the individual bead. Balancing the apparatus at no load is accomplished by moving the weight on the beam after the plunger is set on the bead. The load is applied by allowing free

TABLE 3

CRUSHING STRENGTH OF GLASS BEADS IN POUNDS

20–30 Sieve Size

	Bead						
A	B	C	D	E	F	G	H
Test No. 1							
55	20	96	87	31	37	38	41
69	21	66	95	49	63	51	128
70	22	67	71	47	54	89	41
97	18	20	40	53	60	34	49
18	21	20	55	40	50	33	85
10	46	82	44	20	52	46	92
51	20	64	92	19	85	23	149
15	22	70	75	19	52	20	32
66	43	46	92	21	59	27	52
38	21	60	48	44	60	35	64
Avg 49	25	59	71	34	52	35	68
Test No. 2							
49	18	38	66	38	48	29	48
58	18	29	42	35	33	30	20
51	16	57	53	37	55	52	56
46	15	50	85	52	59	85	50
55	17	55	58	24	72	29	50
63	19	42	64	54	49	56	68
52	18	44	44	26	40	36	68
67	18	49	66	44	34	75	92
56	20	61	48	54	65	21	54
56	18	29	41	38	38	76	46
Avg. 55	18	45	57	40	49	44	54
Test No 3							
49	33	53	63	54	48	30	33
51	30	35	61	29	40	21	32
83	31	44	44	36	26	28	91
67	19	27	62	35	42	49	39
60	35	46	50	65	50	77	35
44	19	35	75	69	54	76	30
79	19	16	82	41	45	27	46
68	19	36	68	15	54	21	89
52	30	58	41	31	27	49	32
80	19	28	52	24	45	36	51
Avg. 63	25	38	60	40	43	41	48
Test No 4							
58	27	46	44	27	33	34	46
70	14	18	62	47	44	58	31
50	29	22	35	34	51	53	34
32	12	12	37	25	64	36	78
56	27	67	55	41	52	77	43
76	20	53	36	42	33	61	68
51	25	39	74	34	55	18	18
51	26	22	80	28	34	20	37
104	17	51	53	19	46	32	104
71	42	66	35	36	44	55	30
Avg 62	24	40	51	33	46	44	49
Test No. 1							
57	13	44	63	11	39	98	12
55	13	75	87	18	47	18	36
54	14	59	62	16	42	14	33
54	16	45	62	20	28	17	30
34	14	103	41	15	45	57	28
26	13	56	52	42	26	68	63
34	17	40	48	18	28	12	57
54	19	40	44	19	37	38	64
50	18	43	53	18	35	44	11
50	10	62	49	10	33	11	4
Avg 47	15	57	56	19	36	38	34

TABLE 3—*Continued*

	Bead						
A	B	C	D	E	F	G	H
Test No. 2							
36	22	21	50	28	39	40	37
61	11	34	26	18	31	40	45
62	6	65	61	55	25	22	34
49	4	20	89	35	27	17	31
63	12	49	46	14	21	35	27
37	12	48	18	49	43	16	42
35	14	24	94	51	21	37	25
33	11	35	19	52	30	21	23
18	4	15	59	18	20	17	89
26	12	43	55	32	27	22	63
Avg. 42	11	35	52	35	28	27	42
Test No. 3							
38	17	21	73	12	28	46	24
48	16	31	48	23	20	38	52
36	16	55	56	23	17	46	43
24	16	17	31	18	38	19	38
52	15	28	28	27	27	12	22
39	15	31	31	20	42	46	18
29	16	32	66	39	33	11	31
47	11	33	30	17	29	39	64
42	19	17	20	39	23	47	17
47	15	27	72	28	33	18	69
Avg 40	16	29	46	25	29	32	38
Test No 4							
72	21	46	27	14	31	17	18
38	11	26	25	18	37	34	98
37	11	26	13	44	16	38	21
15	16	43	49	43	13	30	37
58	15	61	28	43	38	33	71
32	14	19	54	48	21	49	37
25	16	23	66	25	40	23	37
42	14	37	50	18	17	59	37
49	16	24	87	19	37	31	38
18	13	30	79	26	31	15	51
Avg 39	15	34	48	30	28	33	45

flowing dry sand to run into the metal bucket through a glass funnel, having an inside diameter of the outlet of $\frac{3}{16}$ in., at a rate of approximately $2\frac{1}{2}$ lb. per min. The flow of sand is stopped when the bead is ruptured and the sand is weighed in grams For the described equipment the crushing strength is calculated by the following equation:

$$\text{Crushing strength, lbs} = \frac{\text{Wt. in grams} \times 28}{453.6}$$

Beads are selected for the test with tweezers under a 20× glass and ten beads are considered the minimum that should be tested for an average result from each size group. Only spherical beads should be used. The results of the crushing tests are reported in Table 3. Examination of the average values obtained in the crushing test reveals a fairly close correlation with what would be expected for the different beads from their physical structure; i.e., the amount of bubbles. It is thought that the test procedure is sufficiently accurate. The results indicate a wide range of structural strength of the individual beads. With proper attention to the selection of representative individual beads in a sample, suitable averages seem to be obtained by crushing not less than ten beads.

The binder used for all application tests consisted of the standard specification Missouri Highway Department yellow traffic paint. This is a 25-gal. oil length oleo-resinous vehicle paint formulated with a modified phenolic resin and dispersion resin which provides the rapid drying characteristics. The pigment is composed of C. P. Chrome yellow and inert with aluminum stearate to prevent settlement. The viscosity of the paint is held to a maximum of 80 (Ford Cup No. 4 at 80 F.) to provide a suitable consistency for application by the standard equipment used by the Missouri Highway Department. Traffic paint, in Missouri, is applied by flowing the paint through an elongated "fishtail" type nozzle and the viscosity of the paint must be within definite maximum viscosity limits for satisfactory application. The equipment and procedure used have been previously described by Corder (*8*).

The laboratory studies should include, in addition to the separate examination of the paint and the beads, examination of the beaded films to determine such characteristics as initial reflective properties and resistance to atmospheric exposure. The laboratory application of the paint is relatively simple since a doctor blade or similar gage may be used to apply the paint to precise wet film thicknesses. Application of the beads for uniform and accurate coverage poses a difficult problem, and the need for accuracy in bead application for comparative results is obvious. An apparatus for this purpose, shown in Figure 2, was designed during the investigation. The dispenser is a rectangular metal box 4 by 2 by 8 in. with a bevelled bottom having a variable opening across the width at the lower part of the bevel through which the beads flow by gravity. An outside gate which is held securely by a knurled screw can be raised or lowered to change the rate of flow. A sliding inside gate is used to start and stop the flow. The holder is a 4-wheeled carriage running on gear tracks and propelled by a gearhead electric motor. The speed may be varied by changing gears although once the speed is set the dispenser gate may be raised or lowered to control the flow and quantity of beads. Glass panels 6 by 18 in. are used for paint application and are held on the metal base by raised lugs. Calibration of flow of the beads is easily accomplished by making "dry runs" over a metal pan 6 by 24 in. and weighing the beads. The operator slides the doctor blade just ahead of the movement of the dispenser so

TABLE 4
TYPICAL GRADATIONS OF GLASS BEADS

	Bead							
	A	B	C	D	E	F	G	H
Passing Sieve No.	%	%	%	%	%	%	%	%
20	100	100	100	100	100	100	100	100
30	80.7	90.0	95.5	85.2	59.8	89.4	85.1	86.2
50	29.4	22.3	28.2	22.6	6.1	22.6	23.2	24.1
100	0.1	0.06	3.5	3.4	0.4	0.1	0.2	0.2
200	0.06	0.04	0.2	0.2	0.0	0.02	0.02	0.01

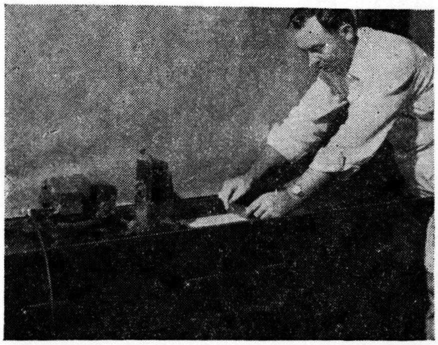

Figure 2. Laboratory Bead Dispenser

that the beads fall promptly on the freshly applied film It is hoped that this type of dispenser can be eventually adapted to field transverse-line application beads over a period of time are reported in Table 5. Figure 4 shows how the panels are mounted on the roof of the laboratory building during exposure

TABLE 5
GLASS PANELS
Hunter Meter Reflectance Values

Age—Days	Without Filter						With Filter					
	1	29	60	88	120	149	1	29	60	88	120	149
Paint	1 5	1.2	2 0	1 2		1 5	1 8	1 2	2 1	1 4		1 7
Bead												
A	16−	12+	9	7+	7+	7	17	13−	10−	8	8+	8−
B	10−	9+	10+	9−	9	9	10−	11−	10+	10−	10	10
C	14	15−	14+	14	13+	13	16−	17−	16+	14	14+	14+
D	17−	19−	20−	18+	17	17	18+	21	21−	18+	18	18+
E	14−	14	15+	14+	13+	13+	15+	15+	16+	15−	15−	14+
H	16+	14	14−	14+	13	13−	16+	15+	16−	15+	14−	13+

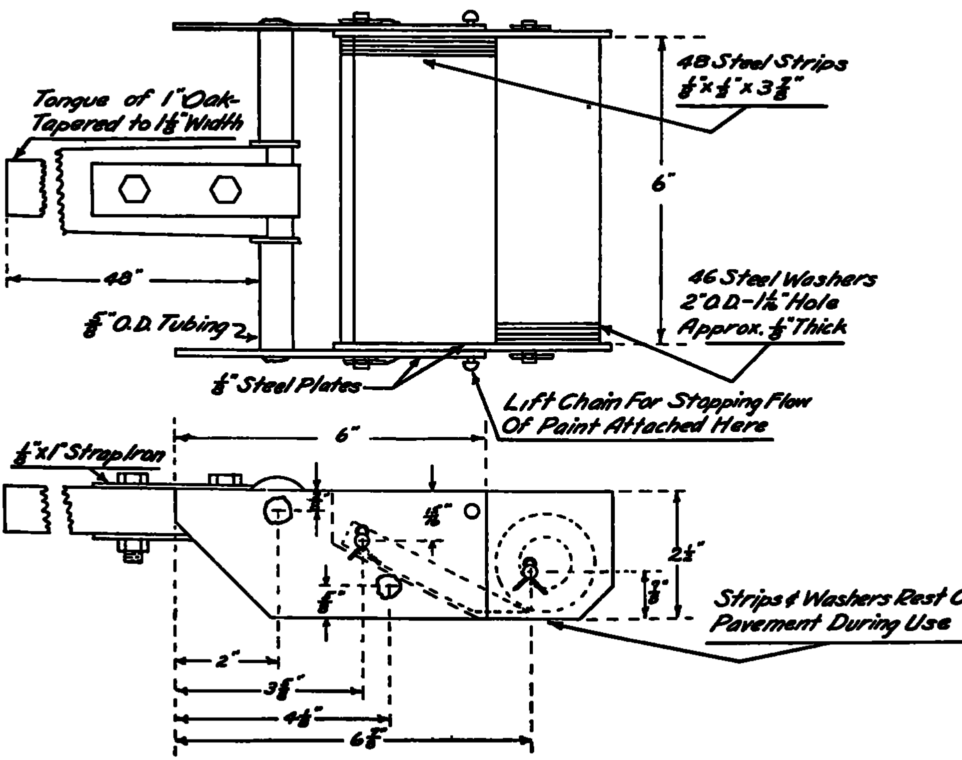

Figure 3. Design of Line-o-graph for Traffic Paint Application

Atmospheric exposure results of panels prepared with the laboratory dispenser showing the effect on the reflective properties of the

On the transverse test section on Route US 50, Cole County, the paint lines were applied by two methods; viz., the line-o-graph and a hand operated flow type striper similar in principle to the regular pavement striping machine The line-o-graph, shown in Figure 3 is a sliding applicator and applies the paint from a reservoir from which the paint flows under a series of freely moving washers. The film so produced averages 7 mils wet thickness. Unfortunately, the viscosity or the body of some paints causes them to remain ridged after flowing from the line-o-graph which adds a variable to the durability evaluation Generally, most paints, including the Missouri standard, flow out to smooth uniform films With the hand striper different film thickness may be applied. During the greater part of the investigation beads were applied with a hand

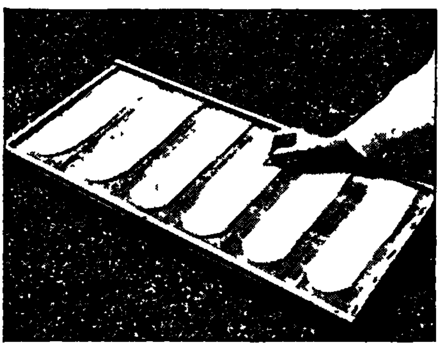

Figure 4. Beaded Paint Stripes for Atmospheric Exposure

operated dispenser borrowed from the Prismo Company. Recent lines have been beaded by carrying the laboratory dispenser by hand over the freshly applied paint These methods have not resulted in a uniform application of the beads and, hence the present attempt to adapt the laboratory dispenser as a mechanical unit for applying beads on the accelerated transverse lines to secure more reproducible results

REFLECTANCE MEASUREMENTS

The Hunter Night-Visibility meter was selected for use in determining reflectance values because of the ready portability and simplicity of the device It is a visual instrument operating on the principle of equality of brightness. It contains a light source which is projected and viewed in the same geometric relationship as that of an automobile's headlights and the drivers' line of sight at a distance of 100 ft The angle of incidence is 88 3 deg and the angle of divergence is 1 2 deg The grazing angle is 2 9 deg.

The operator views the illuminated line through a slit in a mirror which reflects light from a standard illuminated by the same source that illuminates the line The intensity of the reflection from the standard is varied by a control to match the brilliance of the reflection from the line Values are read from a scale on an external drum. A complete description of the Hunter meter is given in an ASTM Preprint (*9*).

Reflectivity of uniformly beaded areas can be readily determined well within the limits of reproducibility of one part in five as stated by the manufacturer of this instrument. Values for worn lines containing only streaks and spots of beads are more difficult to obtain Reflectivity of such non-uniform areas is difficult to judge, as the image line, in the instrument, can be alternately bright and black along its length and a reading of, for instance, 2 will match the dark area while the bright area will match at perhaps 12. A visual balance might be anything from 4 to 8 depending upon the relative extent of each condition. If one condition predominates the tendency is to ignore the other, while if essentially equal or if the alternations occur at several intervals along the image line the tendency is to balance light against dark. The placement of the meter on such lines has a very decided influence on the reading as movement of as little as ¼ in. from side to side or forward or backward will change the balance. It would be obviously incorrect to search out, by moving the meter, the brightest areas.

The possibilities of inconsistencies in readings from date to date are great on spotted or streaked lines as the placement of the meter may vary by enough to change the balance. It is only by marking prominently both the lateral and longitudinal positions and accurately placing the instrument at these locations that the reflectance of the same areas can be measured on different dates Even with the meter positions readily duplicated it is possible that slightly different areas will be viewed, for the adjustment of the meter is rather sensitive, and may be disturbed with handling Evidence of mal-adjustment is that one end of the image line will time after time appear to be shadowed in the matching range. It is recognized that, because of variations in positioning the meter, and resultant variations in the image line when beads are spotted, or streaked, readings are limited in accuracy.

Personal judgment of equality of brightness is also a factor to be considered. While developing procedures for use of the instrument, readings were made by several operators and results compared. It was found that values obtained by different individuals varied over a range of 2 or 3, with an occasional difference of 5, although generally averages checked within one point. A definite tendency was also found for some operators to obtain quite consistently, slightly higher or lower values than others. The chief difficulty arose from the fact that the reflected light from the line was yellow and from the standard, white or gray. The first impulse is to match color instead of brilliance. This can be done by increasing the light from the standard until the image line loses its color distinction and becomes slightly gray by comparison. It was necessary to learn to avoid this tendency and to introduce only a trace of shadow, retaining a definite yellow color in the image line. The manufacturer has now supplied a small yellow filter which may be used when measuring reflectance of yellow lines. However, a series of readings indicated that the operator tended to obtain results about one point higher with the filter. Since readings were yet to be made on lines originally read without the filter, the operator felt that more nearly comparable results would be obtained without the filter and it has not yet been adopted for general use. The filter does eliminate the color differential and facilitates matching for brilliance by one not having had considerable experience with the instrument

VISUAL REFLECTANCE OBSERVATIONS

Visual observations of all lines were made at night by means of automobile headlights and the lines were rated by using an arbitrary scale of 5 deg. of brightness, ranging from very bright to dull. As many as ten observers participated during the time these observations were being made.

On Route 50 at Jefferson City where transverse lines were arranged in groups, the car was placed in position on the shoulder with the headlights trained on a group of lines about 75 ft ahead From this position it was very easy to compare the brilliance of the lines from the car. Ratings were assigned to each line both between the wheel tracks and in the wheel track. Ratings were ordinarily made without consultation Excellent agreement among observers and with instrument readings was obtained on all of these groups.

On Route 66 where the lines were arranged in parallel pairs and the sections were ½ mile long, observers met some difficulty in maintaining a constant visual standard and obtaining consistent results. It was found, naturally, that bright lines under the glare of oncoming headlights would not appear as bright as dimmer lines viewed without such interference. Unavoidable variations in the lines due to the inability of the equipment to maintain absolute control of the rates of application of paint and beads frequently necessitated the "averaging" of several opinions regarding a section while traveling over it. Where differences in brightness were small, observers did not all agree, even in regard to which line of a pair was the brighter. Wherever there was an appreciable difference in brightness, however, there was good agreement among observers and also good agreement with the results obtained by the Hunter meter.

Night visibility observations of no-passing lines were also made on Route 40, Callaway and Montgomery Counties and on Route 50, Pettis and Johnson Counties. Visual evaluation of these lines was difficult because of small differences in reflectivity. The differences which were noted were found to be in agreement with meter readings. These observations served primarily to establish that stations selected for reflectance measurements were representative of the general condition of the lines

VISUAL EXAMINATIONS OF LINES

During the studies of the field performance of beads a number of methods of recording descriptions of the lines and beads was tried. At first the examinations of the lines were rather superficial and the information recorded was generally insufficient to consistently explain variations in reflectance values obtained by the Hunter meter. As studies progressed, detailed examinations of the lines were made periodically and the beads and the paint film condition described following a more or less standardized procedure

The lines were examined by sunlight and the reflection described as being uniform, undulated, streaked, spotted, etc. The rate of application was arbitrarily rated by observation of the brilliance of the reflection as heavy, medium or sparse. Bead appearance and loss were observed under the 20× glass. Bead appearance was described as bright, coated, etched, pitted, bubbly, nicked, crushed, etc., with an arbitrary attempt to rate the degree of each condition. Bead loss was arbitrarily rated from slight, where only a few beads were missing, through moderate and heavy, to extreme, where only a few beads remained. Bead loss is extremely difficult to evaluate as frequently all four of the conditions noted may be found in the area in which the reflectance measurements are made. Paint application was rated as heavy, medium and thin and other general notations included such details as scaling of the paint, with estimates of the extent, and other peculiarities of the application. The kind and condition of the pavement surface such as smooth, granular with aggregate particles showing through, prominent broom or finishing marks, etc., were also noted.

A typical description of a line might be as follows: Sunlight reflection, slightly streaked, application medium. Beads bright, few pitted, many bubbly, bead loss, slight, paint medium, no scale; pavement smooth.

A later description of the same area might be: Sunlight reflection, badly spotted, beads gone from paint in many half-dollar and larger size spots, application otherwise sparse to medium. Beads bright, many bubbly, many nicked, some crushed; loss slight and extreme; paint worn in spots; few quarter size scaled spots.

Such detailed descriptions of the paint lines and beads were found to be very helpful in explaining some of the variations in reflectance values, but strict correlation was found impossible due to the many factors involved. Such observations are essential to any evaluation of the performance of the paint and beads under progressive traffic wear and should be included in any future studies of this type. It has been found that photographs of sunlight reflection, taken from 6 to 8 ft. away, can be satisfactorily used to record the general appearance of the lines at various stages of wear.

PHOTOGRAPHIC RATINGS

Photographic methods were attempted to provide a permanent record of visual comparisons of reflectivity. If a standard procedure could be developed which would reproduce accurately the differences seen by the eye, both a method of rating and of recording such ratings for future comparisons and correlation of successive experiments would be made available

Several preliminary trials were made with a variety of film and lightings. Car lights as a source of illumination were tried but abandoned because of the long exposure required. Photoflash was the best source of light found. It was used in conjunction with car lights since the car lights had little effect on the film but did serve to illuminate the scene and to determine proper focal length. Tests made with several types of film indicated Fast Panchromatic Type B film to give the best promise of desired results.

The first extensive trial was made on Route 66, St. Louis County, a very heavily traveled highway. It proved to be a hazardous job although two highway patrolmen assisted in handling traffic and men were stationed at each end of the operation with warning signs and lights The exposures were made by the open flash method using G. E Photoflash No. 50 in a Heiland reflector. Fast pan film was used and developed in D. K 50. The equipment consisted of a 5 by 7 in view camera equipped with 8¼ in. Goerz Dagor lens used with an aperture of f. 16. Although conscious of the fact that too much light was being used, it was assumed that the reflective quality might diminish at some distance ahead of the camera and only that portion of the negative would be used. This procedure failed to show the differences in the reflective characteristics of the lines. The next trial was made with the same equipment but going to the other extreme. This time a No. 5 (peanut bulb) was used at an aperture of f. 11. This extreme under exposure had to be compensated for in development and thus the film was processed by 30-min. tank development in D K. 50. With this procedure the objectionable pavement background was held to a minimum but the lines themselves were not sufficiently strong to print on anything but a very hard paper. For photographic purposes the transverse accelerated test sections with lines placed close together were found more suitable. These sections permitted the comparison of a larger number of lines on one photograph which could be taken from the shoulder of the road without elaborate safety precautions

Numerous other trials have been made at various intervals and among them infra red and Kodalith Ortho film were used with various results The best results to date have been obtained with No 22 G E Photoflash bulb on fast pan film at f 16 The reflector was shielded so that most of the light was kept off the immediate foreground The film was developed by inspection in Dektol The lines came up strong but retained sufficient variation so that their reflective power could be easily evaluated The background was visible but not strong enough to be particularly objectionable

Usable photographs were obtained by the described procedure but it is thought that still better results can be obtained by using a lens of sufficient focal length to get beyond the effective range of the lights although still covering the lighted zone An example of the type of results possible under careful control is shown in Figure 5

Figure 5. Section 1—Age 55 Days
Beads, Front to Back—A, B, C, D, E, F, F

ACCELERATED TESTS

Route 50 Cole County

The transverse lines on Route 50 at Jefferson City were placed across the north (outgoing) lane of 2-lane pavement just inside the city limits. The pavement grade at the beginning of the section is 0 5 percent, increasing to a grade of 2 1 percent at the end Beyond the section the grade increases to 5.0 percent Because traffic is moving out of the city and on increasing grades, it is ordinarily accelerating moderately Traffic during the time of these tests averaged approximately 2800 vehicles per day of which approximately one half or 1400 per day traveled over the lines.

The lines were placed in groups of six, using a different bead in each line The first group was placed in code order, A, B, C, D, E, F, the second in reverse order, F, E, D, C, B, A, and the third in a random order, C, F, A, D, E, B, the purpose being to avoid the influence of relative position and personal bias when rated visually in headlight beams. Sections 1, 2 and 3 were applied on August 17, 1948. Sections 4, 5 and 6 were duplicates of Groups 1, 2 and 3 respectively and were applied September 3, 1948 The line-o-graph was used to apply the paint and the beads were applied with the right unit of the dual metering type dispenser used on Route 66, St Louis County. The dispenser tended to apply the beads in undulations or waves unless moved at a very rapid rate It is presumed that this was caused by vibration of the dispenser and by the metering flutes on the drum. The wet paint film thickness was approximately 7 mils and the bead application approximately 6 lb. per gal. Sections 1 and 2 were covered by one pass of the dispenser, Section 3 by two passes, however some beads did not bind on the second pass and subsequent intrument readings did not reflect appreciable nor consistent increase in brightness

Stations were marked and Hunter Night Visibility Meter readings were taken in areas in the left wheel track and between the wheel tracks Three readings at 1-in intervals were taken in each area in each line. Average values and ages at which they were obtained

TABLE 6
TRANSVERSE LINES—ROUTE 50 COLE COUNTY
Hunter Meter Reflectance Values

Age—Days	In Wheel Tracks							Between Wheel Tracks									
	2	3	9	16	21	27	30	2	3	9	16	21	27	30	45	55	83
Section 1																	
Beads																	
A	22	23	20	11	8	7	7	25	23	20	17	12	13	13	9	10	8
B	8	10	10	10	8	7	7	9	11	9	8	8	5	5	6	6	8
C	15	22	20	19	16	15	14	17	20	18	18	13	13	14	11	13	15
D	16	22	18	18	17	15	15	17	20	18	17	15	15	16	13	12	15
E	19	20	19	15	13	9	11	20	21	16	16	12	15	16	12	14	12
F	21	26	22	14	11	9	9	24	21	20	13	11	13	12	8	10	11
Section 2																	
A	24	26	21	12	12	10	9	23	23	23	13	14	12	13	12	13	12
B	11	14	12	9	7	9	9	11	11	11	10	10	8	10	8	9	10
C	18	16	18	14	13	10	13	17	16	15	14	13	14	13	14	12	11
D	19	19	19	18	14	14	15	19	18	17	15	15	15	16	14	15	14
E	18	15	15	8	12	6	8	17	16	15	15	14	13	14	12	11	9
F	16	15	12	9	9	8	8	18	19	14	12	12	10	10	10	9	11
Section 3																	
A	27	20	20	13	12	12	11	25	19	20	14	13	14	14	13	12	12
B	11	10	10	8	7	5	6	9	8	9	8	7	8	8	7	8	8
C	18	16	17	18	17	15	14	16	14	14	14	14	12	14	13	13	11
D	20	17	19	17	15	13	14	19	16	16	13	14	14	15	13	14	14
E	17	14	8	6	5	5	4	16	12	13	9	11	12	11	10	3	4
F	19	20	19	13	10	8	8	21	18	18	14	12	13	12	10	10	8
Averages																	
A	24	23	20	12	11	10	9	24	22	21	15	13	13	13	11	12	11
B	10	11	11	9	7	7	7	10	10	10	9	8	7	8	7	8	9
C	17	18	18	17	15	13	14	17	17	16	15	13	13	14	13	13	12
D	18	19	19	18	15	14	15	18	18	17	15	15	15	16	13	14	14
E	18	16	14	10	10	7	8	18	16	15	13	12	13	14	11	9	8
F	19	20	18	12	10	8	8	21	19	17	13	12	12	11	9	10	10

Age—Days	1	4	10	14	20	28	38	1	4	10	14	20	28	38	66
Section 4															
Beads															
A	25	21	17	16	17	12	5	18	18	18	16	16	16	13	11
B	12	14	13	11	11	10	5	13	13	12	15	12	12	13	13
C	18	18	17	15	16	17	10	18	17	16	14	16	15	16	15
D	19	19	17	16	16	17	11	19	19	17	16	16	15	17	16
E	16	14	13	12	8	10	6	14	14	13	14	13	13	12	10
F	21	17	15	15	13	13	7	15	15	15	15	14	14	14	11
Section 5															
A	20	18	14	15	12	9	7	20	19	18	17	14	14	13	10
B	10	9	8	7	7	4	4	12	14	11	12	12	11	11	12
C	16	16	15	12	15	14	11	15	14	16	13	14	16	15	12
D	17	16	14	14	14	12	8	17	17	15	16	16	13	16	14
E	7	7	5	6	3	4	3	13	14	12	11	12	11	11	6
F	17	14	10	10	7	5	5	17	15	14	17	12	12	14	7
Section 6															
A	14	12	10	9	7	6	2	17	17	16	15	12	13	10	9
B	10	8	8	7	9	6	3	9	10	9	10	9	8	10	9
C	14	14	15	15	14	12	10	11	14	13	13	12	12	13	11
D	17	19	19	18	17	17	10	15	16	16	15	13	15	18	14
E	14	14	12	12	8	6	5	12	12	13	11	14	10	12	7
F	19	17	16	14	13	8	8	17	16	18	17	14	14	14	11
Averages															
A	20	17	14	13	12	9	5	18	18	17	16	14	14	12	10
B	11	10	10	8	9	7	4	11	12	11	12	11	10	11	11
C	16	16	16	14	15	14	10	15	15	15	13	14	14	15	13
D	18	18	17	16	16	15	10	17	17	16	16	15	14	17	15
E	12	12	10	10	6	7	5	13	13	13	12	13	11	12	8
F	19	16	14	13	11	9	7	16	15	16	16	13	13	14	10

are shown in Table 6. Averages of Sections 1, 2 and 3 and of 4, 5 and 6 are shown graphically in Figure 6. No systematic examinations were made with the magnifying glass or in sunlight but it was noted that the bead application was not uniform in many lines. Variations from position to position ran as high as 4 or 5 points. Usually, however, they did not exceed 2 or 3, which could be considered quite erratic. Thus readings in these areas were discontinued in Sections 1, 2 and 3 after 30 days and in Sections 4, 5 and 6 after 38 days. Wear in areas between wheel tracks was much less severe and readings were continued to 83 and 66 days respectively. Readings at greater ages should have, and would have been made, had weather and road surface conditions been favorable.

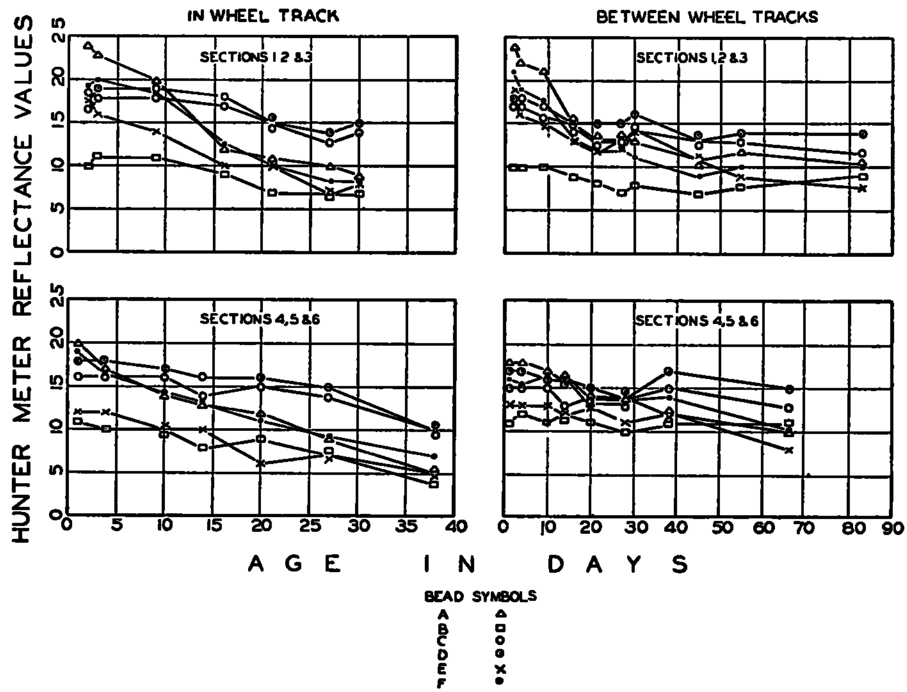

Figure 6. Reflectance Values—Route 50, Cole County

satisfactory. Extreme variations were usually checked by rereading all positions.

It should be noted that these lines involve two rates of acceleration of wear as compared to the regular beaded "no-passing" lines as applied in Missouri. First, the paint film thickness was less than one half that of regular lines and the beads were underbonded, and second, the parts of the lines through the wheel tracks were subjected to full traffic wear. The areas in the wheel tracks lost beads and the paint scaled or wore away rapidly. Loss of beads and paint was not uniform and the areas became progressively more spotted and streaked until Hunter meter reflectance values were difficult to determine and were

In order to evaluate the characteristics of a new bead, identified as Bead H, which became available after Test Sections 1 to 6 inclusive were completed, three new series of transverse lines were applied across half the width of the pavement on Route 50 west of Jefferson City in 1949. Traffic, during the time of these tests, averaged approximately 3200 vehicles per day, of which an estimated one half passed over the lines. Sections 7 and 8 were applied May 26. Paint was applied in Section 7 by use of the line-o-graph and in Section 8 by use of the hand propelled nozzle striper. Beads A, B, C, D, E and H were used and applied by means of a metering type dispenser. The wet paint film thicknesses were approximately 7 mils for Section 7 and 25 mils for Section 8. Bead coverage was at the rate of approximately 6 lb. per gal. of paint.

Section 9 was applied July 21 using Beads C, D, E and H. This section was abandoned because the lines were considered unsatisfactory for reflectance measurements. Traffic had been permitted to pass over the lines about 30 min. after application, causing variable damage. The lines did not have the desired uniformity of application of beads and the lines on which one type of bead was used were found to be entirely unsuitable for reflectance measurements For these reasons, no evaluation of the lines was made

Section 10 was applied July 22 and was a duplication of the abandoned section. The beads were applied by the laboratory dispenser carried by hand and a more uniform distribution was generally obtained. Traffic was kept off the lines for 5 hr. to allow the paint to dry more thoroughly. The wet paint film thickness was approximately 7 mils and bead coverage was approximately 6 lb. per gal. of paint.

Reading positions on the selected lines were carefully marked so that the instrument positions laterally as well as along the line could be readily duplicated. Five readings at 2-in. intervals were made in the wheel track and between the wheel tracks. The results obtained are shown in Table 7 and Figure 7.

The stations in the wheel tracks in Section 7 were read at 1 and 12 days only. At 20 days these lines were so worn that paint and beads remained only in short, narrow streaks and a few "quarter" and "dime" size spots, and no reflectance measurements were attempted. It is judged that values of the order of 4 to 6 might have been obtained in some positions.

TABLE 7
TRANSVERSE LINES—ROUTE 50 COLE COUNTY
Hunter Meter Reflectance Values

	In Wheel Tracks										Between Wheel Tracks									
Age—Days	1	5	12	20	29	42	60	76	96	117	1	5	12	20	29	42	60	76	96	117
Section 7 Line-o-graph Striper																				
Bead																				
A	12		5								14		11	9	9	7	5	4	3	
B	10		8								11		11	10	11	8	8	7	4	
C	14		11								14		14	16	17	14	13	13	11	
D	14		9								14		16	15	16	12	9	9	5	
E	10		6								11		11	8	8	6	4	3	2	
H	16		14								18		16	18	19	16	13	14	13	1
Section 8 Nozzle Striper																				
A		11	8	7	7	8	6	5	5	5		15	12	11	10	9	8	7	8	8
B		4	4	5	4	4	4	3	4	5		11	8	11	11	11	10	9	11	11
C		10	8	10	11	12	11	10	11	10		14	13	14	16	14	11	12	14	14
D		9	8	10	10	10	9	8	9	9		15	12	15	16	14	13	13	15	14
E		12	12	12	10	7	6	5	4	3		15	11	14	16	15	13	13	15	13
H		15	14	16	16	15	13	12	14	11		13	9	15	14	14	14	14	16	15
Section 10 Line-o-graph Striper																				
Age—Days	1	3	6	10	13	20	29	39	47	60	1	3	6	10	13	20	29	39	47	60
Bead																				
C-1	15	15	15	13	12	10	4	2			15	13	11	13	14	14	15	15	12	8
C-2	13	13	12	11	11	8	3	2			13	12	9	12	12	13	13	14	11	9
D-1	17	17	17	16	17	17	15	11	10	3	16	14	12	13	14	15	16	18	17	17
D-2	16	17	16	17	17	17	15	8	4		16	14	11	14	15	15	16	19	16	17
E-1	16	16	16	15	14	12	8	3			15	14	11	14	14	14	14	13	12	7
E-2	17	16	15	14	13	11	8	6			15	14	12	14	14	14	15	15	12	12
H-1	21	21	20	20	20	18	15	7			21	19	15	19	20	19	20	21	18	18
H-2	21	20	20	19	18	18	15	8			22	19	15	20	19	19	20	21	19	19

Particular effort was made to obtain reflectance values, even though they were very erratic, for lines in such condition between the wheel tracks in this section, and both in and between the wheel tracks in Sections 8 and 10, and measurements were continued as long as any appreciable areas of beads were present

nicked and crushed beads were found in all the lines In general, Beads C, D and H withstood the shattering effects of traffic better than Beads A, B and E Bead loss in the wheel tracks ranged from moderate to heavy for Beads C, D and H and from heavy to extreme for Beads A, B and E. Between the wheel tracks, loss ranged from slight for Beads C, D

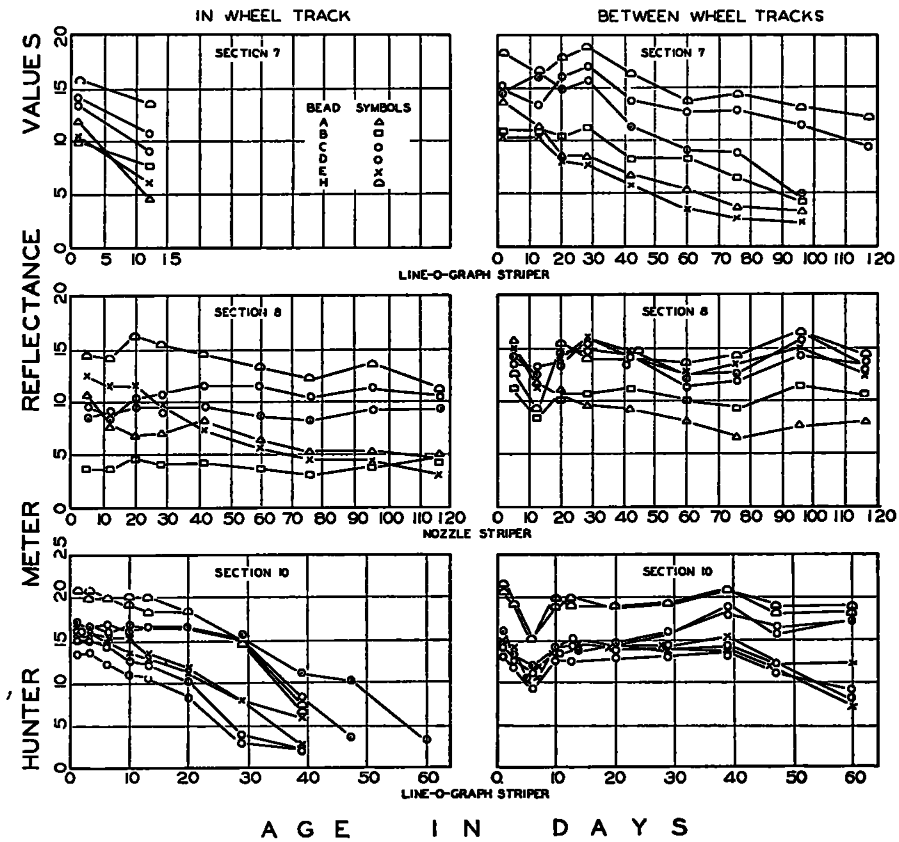

Figure 7. Reflectance Values—Route 50, Cole County

In Section 8, placed with the nozzle striper, the beads were immediately ironed into the paint in the wheel tracks so that, with the exception of Bead H, even the larger beads were ¾ or more submerged. The line in which Bead H was used showed considerably less bead submergence and it is presumed that the paint film might have been somewhat thinner than in the other lines Even though heavily embedded, the beads exhibited the effects of traffic impact and, at later ages, a great many

and H to slight to moderate for Beads B and E and to heavy for Bead A Bead A quickly became badly etched both in and between the wheel tracks.

In Section 10, placed with the line-o-graph, the lines for Bead C, as noted by initial observation, either received a low rate of bead application or else, for some other reason, failed to show initial bead retention equal to the other lines For this reason the reflectance data for Bead C in this section, while reported is not considered in the final evaluation. The other lines did show satisfactory application During the first 20 days the lines in which Beads C and E were used became very spotted in the wheel tracks due to uneven loss of beads from the paint film. There was no scaling of the paint. The lines in which Beads D and H were used developed only slight spottiness but there was some slight scaling in these lines. Between the wheel tracks the lines had maintained their original appearance with only slight bead loss. Subsequently all the lines in the wheel tracks became progressively more and more spotted and worn until few beads and little paint remained. Between the wheel tracks, the lines in which Bead D was used maintained their uniform appearance, while some spottiness was beginning to appear in the lines in which Bead H was used. Line E-1 had become extremely spotted while E-2 was less so The lines in which Bead C was used also were extremely spotted.

UNACCELERATED TESTS

Route 66, St. Louis County—The lines on Route 66 were placed one on each side of the centerline of the 4-lane pavement extending from St. Louis City Limits westerly for 10.8 miles. As previously stated, this series was designed as a less accelerated check of the trends established by the transverse stripes applied on Route 50 at Jefferson City.

Traffic was very heavy and provided considerable acceleration of wear in comparison with regular "No-Passing" lines. The following 1948 traffic counts were recorded:

	vehicles per day
Beginning of Section 1	12,906
End of Section 10	10,625
Beginning of Section 11	9,306
West end of Section 20	7,273

Short distances at two important intersections and over the Meramec River Bridge had previously been striped. These were treated as exceptions and omitted from the study in order to avoid the effects of painting over remnants of previously applied lines All sections except 19 and 20 were ½ mile long. Sections 19 and 20 were approximately ¼ mile long.

The lines were applied by regular striping equipment on August 11 and 12, 1948 Table 8 shows the arrangement and the pairing of the beads Sections 1 through 16 were applied by use of two paint nozzles and a metering type double unit dispenser. Sections 17 through 20 were placed with a single nozzle and the gravity flow bead dispenser. Both dispensers apply the beads to the paint lines immediately after the paint has been applied to the pavement. The north line on these four sections was placed first, then the equipment was returned to the beginning of Section 17 and the south line applied. The paint supply in the tanks became exhausted at 0 1 mile beyond the beginning of Section 15 and the tanks were refilled with paint meeting the same specifications but manufactured at a later date. This paint was used for the remainder of Section 15 and for the remaining sections. During application with the dual equipment it appeared that the north (right) side dispenser was feeding more beads A check of the two bead tanks at the end of Section 4 indicated also that this was true. The south line, as applied, did not have a strictly uniform section The paint appeared thin in a strip about 1½ in wide, ½ in. from the north edge and the south half of the line appeared to have a greater concentration of beads. The north line appeared uniform in section with a uniform lateral distribution of beads.

Wet paint film measurements on metal plates between Sections 13 and 14 showed the thickness of the north line to be 18½ mils. The measurement of the south line was made in the thin portion in the north half of the line and showed it to be 13 mils. Measurements in Section 18 gave results of 17 and 18 mils for the north line and 18 mils for the south line. Beads were applied in Sections 1 through 16 at the rate of 4 75 lb per gal. and on Sections 17 through 20 at about 5 lb per gal.

Samples of all lines were obtained on sized paper by securing 11- by 22-in paper panels to the pavement in the path of the striper and protecting the samples with barricades until they had dried sufficiently to permit handling. These samples were retained and are still available for observation as representing the characteristics of the lines as applied

Stations for reflectance measurements were marked on each line at about the mid point of each section Three readings at 6-in intervals were taken on each line at each station The number of readings on each line at each station was later increased to 5, all spaced at 6-in intervals The results are shown in Table

8 and Figure 8. The first reflectance measurements of these lines were made at 2 days. Since it was the first experience with the Hunter Night Visibility Meter on this work, generally two or three operators collaborated and any results which were obviously out of line were checked by rereading. It was found

TABLE 8
DUAL CENTER LINE
ROUTE 66—ST LOUIS COUNTY
Hunter Meter Reflectance Values

Sec.	Line	Bead	Age—Days					
			2	14	48	68	126	240
1	N[a]	B	11		10	11	12	
	S	A	11		9	10	10	
2	N	A	11		10	9	9	
	S	B	10		10	10	11	
3	N	C	11		11	11	8	
	S	A	11		9	8	7	
4	N	A	11		10	9	5	
	S	C	12		10	10	10	
5	N	D	12		13	13	5	
	S	A	12		9	9	9	
6	N	A	12		10	10	6	
	S	D	12		11	13	11	
7	N	E	12		13	12	6	
	S	A	11		10	11	8	
8	N	A	11		11	9	5	
	S	E	12		12	11	9	
9	N	E	11			13	9	
	S	B	10			10	11	
10	N	B	12			10	8	
	S	E	12			13	11	
11	N	D	11			14	11	
	S	C	11			12	8	
12	N	C	10			12	5	
	S	D	11			12	11	
13	N	E	12			11	6	
	S	C	11			13	10	
14	N	C	11			13	8	3
	S	E	10			12	8	3 & 7
15	N	D	20	17	17	16	12	4
	S	B	17	16	12	13	12	7 & 11[b]
16	N	B	16	16		13	14	8
	S	D	16	15		16	15	9 & 14[b]
17	N	C	21	20	17	15	6	3 & 10[b]
	S	A	16	17	12	12	11	7
18	N	A	19	19	14	14	13	8
	S	D	14	14	10	15	14	13
19	N	D	18			17	17	17
	S	E	17			14	14	7
20	N	D	16			16	16	14
	S	E	14			13	13	5

[a] N—North Line
S—South Line
[b] Edge of Line

that the initial readings for Sections 1 through 14 were essentially the same regardless of the type of bead used while greater differences and higher values were obtained on Sections 15 through 20

As mentioned previously, two lots of paint were used on the Route US 66 section and it was noted that initial reflectance values of the beads applied on the second lot of paint were considerably higher than the first. The first lot of paint, used on Sections 1 through 14, was approximately 1 yr. old while the second lot used on the balance of the sections had been manufactured just several days before application. Examination of the lines under the 20× glass indicated that when older paint was used the beads were more thoroughly enveloped because of apparent paint "upcreep" whereas, with the newer paint, the beads, although satisfactory embedded, had less pronounced envelopment of paint around the upper surfaces. This characteristic was noted at various times on other field sections and can be attributed to certain properties of the paint

As discussed previously, the Missouri standard specification traffic paint contains dispersion resin to provide rapid drying characteristics This dispersion resin consists of a highly polymerized oleoresinous material dispersed in a carrying agent. It must be fully compatible with the varnish used in formulation The paint is made by introducing all constituents in a pebble mill and allowing sufficient grinding period to produce a smooth well ground paint The resulting paint has tenacious adhering qualities and accordingly acts as a good binder for glass beads. The paint, however, is unorthodox since, although appearing to provide a smooth film, it is somewhat thixotropic because all of the fine particles of the dispersed resin are not in complete solution. When stored at temperatures approximating 70 F. or lower the paint retains its original viscosity but when stored at higher temperatures, such as are encountered during summer months, the efflux or flow viscosity as gaged by the Ford Cup may show a considerable decrease. When the flow viscosity decreases, the consistency as measured by the Stormer viscometer will show a corresponding decrease but to a much lesser degree, such that paint which has been reduced in flow viscosity to as low as 15 (Ford Cup No. 4 at 80 F.) has sufficient body to provide well defined and satisfactory lines. Apparently the decrease in viscosity is caused by a further solution effect of the dispersed resin when maintained at elevated temperatures The decrease of consistency or body permits the beads when added by surface application to immerse more easily and deeply in the older paint thus causing more paint to remain around them as the film dries and shrinks away The lower efflux viscosity of the older

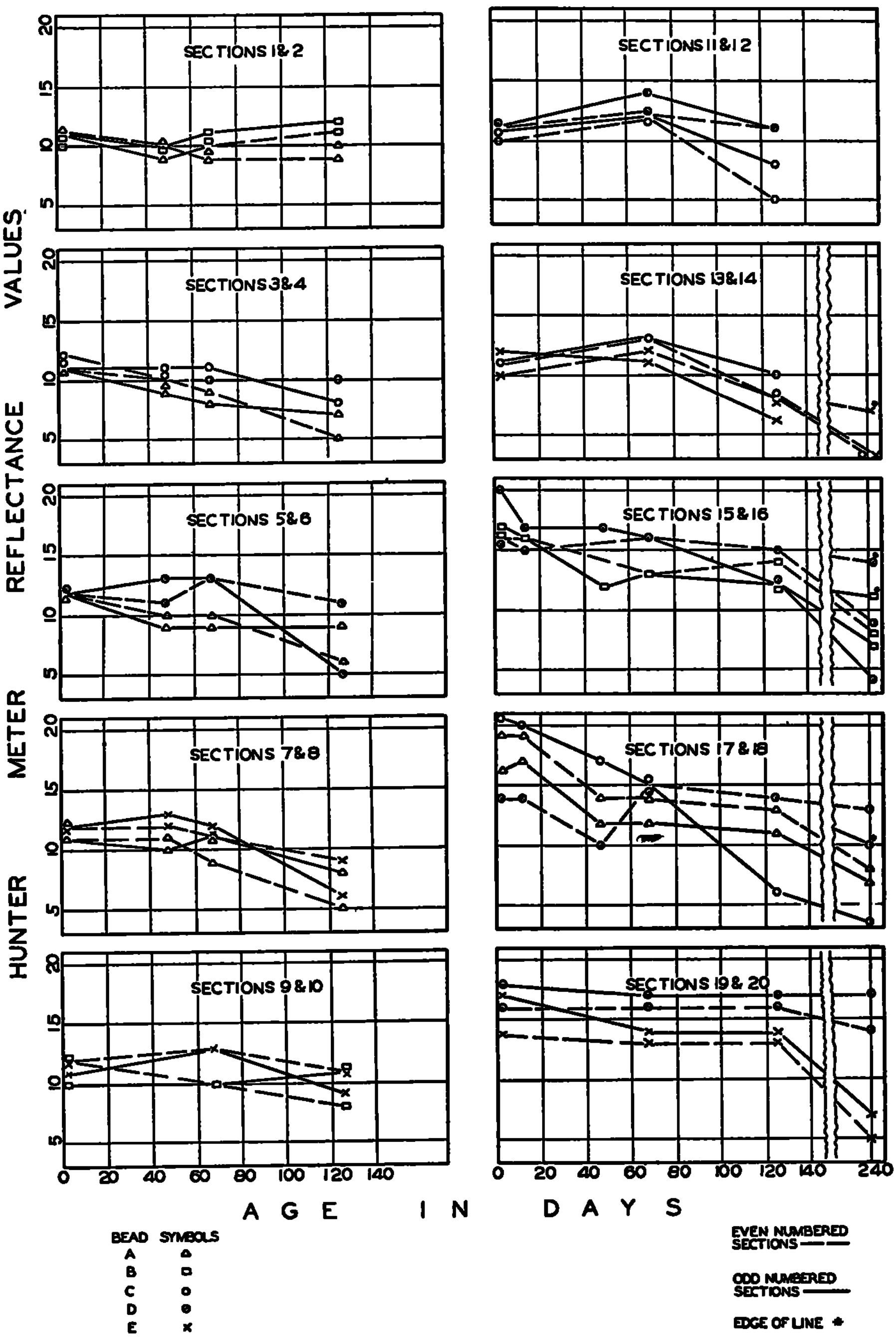

Figure 8. Reflectance Values—Route 66, St. Louis County

paint would also be expected to increase its wetting characteristics and promote greater envelopment of the beads Differences in durability of the beaded paint lines using either new or older paints have not been significant.

These lines were subjected to considerable traffic wear as it was observed that vehicles tended to travel on or cross the lines when passing others, particularly when opposing traffic was light For the first 68 days, the lines in Sections 1 through 14 showed, in general, slight effects of traffic wear There was some bead loss and some "polishing" or decrease of envelopment of the beads. The lines for Sections 15 through 20 showed somewhat greater bead loss. Also, more frequent occurrence of uneven image lines in the Hunter meter were noted. Observations of Sections 17 and 18 both at night and in sunlight, showed that these lines were not uniform throughout the sections. The south line of Section 18 was definitely underbeaded for considerable distances Station 18 fell near the turnout to a cabin camp and was so marked with mud and sand that it was necessary to take readings 300 ft to the west with very much higher results for the south line, which indicated also that that line at the original station had been under-beaded. The north line in Section 17 was observed to be wearing very thin in the center This line was only 3½-in wide and the paint film was very much heavier along the edges Subsequently this line wore in such a manner that only two narrow but bright streaks were visible at night. This wear would indicate a thin paint film in the center with markedly less envelopment of the beads and could thus account for the relatively high initial reflectance values obtained. The characteristics of these lines are such that exclusion of the data might be justified

At 125 days all sections were showing marked wear, some scaling of the paint film and moderate to extreme bead loss Lines at some stations adjacent to graveled parking strips or side road approaches were particularly affected At this age it was found that the inequalities in application of paint and beads were becoming rather pronounced The south line was generally retaining reflectivity better than its companion north line, although the characteristic thin streak near the center of the line was wearing very thin. Numerous cases of uneven image lines in the Hunter meter, requiring careful judgment of balance, were noted

Final examination of the lines was made at 240 days after a winter of service. By this time the lines in the first 13 stations, over which traffic was heaviest, were so worn that paint and beads remained only in spots and streaks, the streaks ordinarily being along the edges of the stripes The paint was frequently gone entirely for several hundred feet or was merely a stain with a few small beads held in depressions in the pavement. Sections 14 to 20, inclusive, when observed at night, appeared to be in progressively better condition and reflectance measurements were attempted on these sections On Sections 14 to 16, inclusive, the uneven lateral distribution of paint and beads in the south line was so pronounced that measurements were made, both with the instrument centered on the line and with it centered on the south one-third of the line. On Section 17, the south line had fairly uniform lateral distribution but the north line was worn in the center with ½-in. bright streaks along each edge Measurements were made on one of these edges Both edge and center values are shown in Table 8 and on Figure 8 Lateral distribution of paint and beads at Stations 18, 19 and 20 were reasonably uniform although the lines were worn and bead loss heavy except for the north line in Section 20

Route P, St Louis County—On August 13th a series of 50-ft. sections were applied on Route SP, St Louis County, using Beads A, B, C, D, E and F These sections were designed to supplement the US Route 66 sections by providing tests at the mid-point of the traffic lane instead of adjacent to the center line. Because of the short lengths of the lines the paint was applied by means of a motor-driven, hand guided pressure spray striper. Beads were applied by gravity flow through a "fish tail" orifice attached to the striper

These sections were abandoned but produced the following information Longitudinal sections of short length, applied near intersections where traffic must stop, were subject to coating with oil drippings and soil. They were also subjected to selective and excessive wear from granular material carried onto the pavement. The light motor-driven striper did not produce a uniform bead application because of excessive vibration. These conditions did not permit satisfactory evaluation of reflectance although the original reflectance measurements obtained from sections having satisfactory bead coverage checked results obtained on other installations

Route 40, Callaway and Montgomery Counties—Lines were applied in no-passing zones on September 20, 1948, in the south lane of the two lane pavement on Route 40, between Kingdom City and Mineola in Callaway and Montgomery Counties to compare a new bead identified as "Bead G" with Beads C & D under average field conditions Traffic over these sections averaged approximately 2600 vehicles per day of which an estimated one-half traveled in the lane in which the lines were applied.

The lines were applied in three groups or sections The first section on which Bead D was used was 4 5 miles long and included ten no-passing zones, the second section, on which Bead G was used was 5.1 miles long and included six no-passing zones; the third section on which Bead C was used was 4.6 miles long and included thirteen no-passing zones These lines were placed, in accordance with Missouri practice, in the center of the lane. Regular striping equipment was used, and the beads were applied by a metering type dispenser. The wet paint film thickness was 15–18 mils and beads were applied at the rate of approximately 4 lb. per gal.

Three reading stations in Sections 1 and 2 and four stations in Section 3 were selected and marked. Five readings spaced at 6-in. intervals were made at each station. First readings were made on one day. Detailed examinations of the lines at the reading stations were made under a 20× glass and observations by reflected sunlight were also made and recorded. At the time of the first examinations it appeared, under the 20× glass, that the bead application had been somewhat sparse or that a considerable number of the beads were submerged in or covered over by the paint. The visible beads were widely spaced and no appreciable amount of upcreep was evident.

Subsequent readings and examinations at 17 and 64 days showed that the lines were maintaining the original reflectivity and appearance. Readings and examinations at 144 days showed slight but consistent reductions in reflectivity, generally slight to moderate bead loss, and some intermittent scaling of paint Lines on curves and hills that had been cindered during the winter had become badly worn and scaled. It was necessary to move Station 7 fifteen feet west in order to read an unscaled area Some reading areas at other stations were slightly scaled although there was no scaling at some stations

Readings at 187 days indicated recovery of reflectivity to approximately former values for Beads G & C and slight recovery for Bead D. Readings at 263 and 319 days revealed no significant reductions during that period, nor were there any significant differences in the appearances of the lines except that those on curves to the left were showing increasing wear and scaling of paint. The results obtained are shown in Table 9 and Figure 9.

Route 50, Pettis and Johnson Counties—Lines were applied in no-passing zones on November 30, 1948 in both lanes of the 2-lane pavement on Route 50 between Sedalia and Warrensburg in Pettis and Johnson Counties to make additional comparisons under field conditions of Beads C, D, G and E. Traffic over these sections averaged approximately 2300 vehicles per day of which it is estimated that one-half traveled in each lane

The lines were applied in four groups as follows.

North Lane — Sedalia - Knobnoster — 19 miles—'G' Bead
North Lane—Knobnoster-Warrensburg—10 miles—'D' Bead
South Lane—Warrensburg-Knobnoster—10 miles—'C' Bead
South Lane—Knobnoster-Sedalia—19 miles—'E' Bead

A 5-mile section of bituminous pavement between Sedalia and Knobnoster was striped at the same time but was considered an exception and not included in the study.

These lines were placed, in accordance with Missouri practice, in the center of the lanes. Regular striping equipment was used. The beads were applied by the gravity dispenser which did not give perfectly uniform lateral distribution Approximately 3½ lb. of beads per gallon of paint were applied on these lines.

TABLE 9
NO PASSING LINES
ROUTE 40—CALLAWAY & MONTGOMERY COUNTIES
Hunter Meter Reflectance Values

Station	Bead	Age—Days						
		1	17	64	144	187	263	319
1	D	15	12	12	10	11	9	11
2		15	13	14	10	10	9	10
3		12	13	13	9	10	11	11
Average		14−	13−	13	10−	10+	10−	11−
4	G	12	13	12	10	12	10	11
5		11	10	11	10	11	11	11
6		10	9	10	8	9	7	10
Average		11	11−	11	9+	11−	9+	11−
7	C	10	10	11	8[a]	10[a]	9[a]	10[a]
7A		12	11	11	9	11	10	11
8		9	10	10	9	9	9	8
9		11	11	12	11	11	10	11
Average		11−	11−	11	9+	10+	10−	10

[a] New Station Old Station Scaled—not representative of lines

passed over the plates. The measurements showed rather wide variation ranging from approximately 13 mils to 21 mils The thickness of the film varied inversely with the speed of the striper which evidently was reduced somewhat when traveling upgrade and increased when traveling downgrade.

Three reading stations were selected and marked in each section, in the same line or a line near the one in which the film thickness measurements were made. Five readings spaced at 6-in. intervals were made at each station. The first readings were made at 6 days. Examination under the 20× glass revealed considerable "upcreep" and that the beads were almost completely enveloped in paint. All lines except at Stations 7, 8 and 9 had about the same appearance. At Stations 7, 8 and 9 the beads were obviously smaller and were even further enveloped except for a few extremely large beads which were only about half submerged. The bead distribution was not uniform laterally. Heavier coverage in three streaks was evident both in sunlight and under the magnifying glass. Bead loss was very slight, only an occasional empty bead cup being observed.

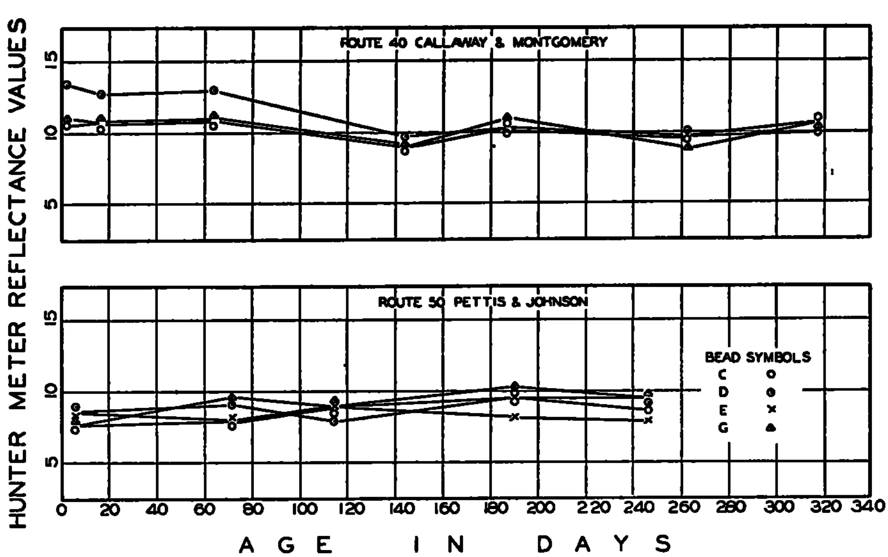

Figure 9. Reflectance Values—Route 40, Callaway-Montgomery Counties Route 50, Pettis-Johnson Counties

Wet paint film thickness measurements were made on metal plates in each section, the flow of beads being interrupted while the striper

Later examinations and measurements

showed that the lines had maintained their reflective values, even perhaps increasing slightly. More beads were visible under a magnifying glass and envelopment had been reduced. The larger beads remaining were about ⅜ to ½ exposed While there was some variation between stations, bead loss was slight to moderate where unaffected by scaling. The streaked appearance in sunlight reflection had largely disappeared but the application appeared sparse.

TABLE 10
NO PASSING LINES
ROUTE 50—PETTIS & JOHNSON COUNTIES
Hunter Meter Reflectance Values

Station	Bead	Age—Days				
		6	72	115	191	246
1	G	8	9	9	10	10
2		7	10	9	10	9
3		8	10	9	11	9
Average		8−	10−	9	10+	9+
4	D	9	9	9	10	10
5		8	10	8	10	9
6		8	9	8	9	9
Average		8+	9+	8+	10−	9+
7	C	7	4[a]	3[a]	9[b]	9[b]
8		8	8	9	10	9
9		8	8	9	10	9
Average		8−	8	9	10−	9
10	E	8	8	9	9	6
11		8	9	9	9	9
12		9	7	9	7	9[c]
Average		8+	8	9	8+	8

[a] Entire line 'severely scaled—Not representative
[b] New Station—1 0 mile east.
[c] Severely scaled—Moved 40′ East

At both 191 and 246 days Beads C, D and G were approximately equal in reflectance while Bead E gave consistently slightly lower results. With the exceptions of those lines on hills and curves, the lines appeared to be in condition to give many more months of service. The results obtained are shown in Table 10 and Figure 9.

DISCUSSION OF LABORATORY DATA

Studies of the effects of chemical composition of glass on durability and reflectance are difficult and are probably outside the logical field of many highway laboratories. Special techniques and expert chemical work are required. For these reasons it seems desirable to approach this subject with care and to develop control tests for specification purposes which do not involve complete chemical analysis. For example; should only the silica content, in conjunction with physical characteristics such as crushing strength, gradation, refractive index and reflectance be deemed necessary to provide proper control, the problem is not too complex since relatively simple methods to obtain reproducible results for this constituent are available. If, however, complete chemical analysis is considered necessary the problem is of major proportion in the case of unusual compositions because of the long tedious methods which must be followed and the need for various methods of attack dependent upon composition. Even if complete chemical analyses are obtained, correlation with crushing strength, refractive index, chemical durability, etc. is difficult and some composition requirements which might be specified might unduly restrict the development of reflective materials. Physical tests of the product, specifically measuring the characteristics desired, are much to be preferred to attempts to predict physical characteristics from a complex chemical composition.

Glasses of orthodox silica-soda-lime composition such as Beads B, C, D and E, do not present any particular difficulty in chemical analysis and the published ASTM methods are fully adequate. The low silica glasses containing fluorine and various metallic oxides such as Beads A, F, G and H present an entirely different problem. Spectrochemical analysis for qualitative determination of metals present seems to be the most expeditious and rapid means of approach This may be followed by gravimetric chemical analyses, but extensive search may be found necessary to locate suitable and reliable methods.

As would be expected, the high silica glasses in Beads B, C, D and E were chemically resistant, as determined by acid attack, and were not affected by atmospheric exposure. Beads A and F on the other hand were readily decomposed by 1.1 sulphuric acid solution and were attacked by water with the formation of white deposits. These white deposits were often apparent on the A bead after application in the paint but it was not determined definitely whether such deposits were caused by moisture or attack by the fatty acids in the paint Moisture was suspected as being the contributing factor. The laboratory-prepared glass panels under atmospheric exposure showed a significant decrease in reflectance values over a period of several months for the A bead (F bead was not used on these panels) in comparison with B, C, D, E and H. It is interesting to note that the low silica glasses which had improved resistance to moisture and, in different degrees to acid attack, contained additional oxides such as titanium, zirconium and zinc This was noticeably true in the case of Beads G and H. From these findings it may follow that glass beads which, on laboratory examination, indicate any weakness in resistance to moisture or dilute acid, should be viewed with suspicion until service tests have proved their durability.

It is interesting to note that the refractive indexes of the low silica glasses are consistently higher than those with high silica. While this characteristic is important from a reflectance standpoint it must be realized that it is a property of the glass, per se, and not of the finished bead Surface imperfections such as scratching, scoring and pitting and structural defects such as bubbles, incipient fractures and milkiness caused by myriads of fine seeds or uncombined oxides all contribute to lowering the reflex-reflection efficiency of the beads regardless of the refractive index of the glass Bead B is an excellent example of the depressing effect of surface defects on initial reflectance values while Bead E, which although showing no particular surface defects contained a preponderance of bubbles, showed rather poor resistance to traffic wear with resultant greater loss of reflectance as compared with Beads C and D, which did not have similar defects. In the case of Bead E, its loss of reflectance was consistently greater when the beads were placed in the thinner paint films provided by the line-o-graph on the accelerated pavement test sections. This fact seems pertinent in emphasizing the structural weakness of the bead as the magnitude of reflectance loss was lessened when the beads were placed in normal paint films (wet thicknesses of the order of 18 mils) in which case the paint was undoubtedly providing some protection against bead damage

The beads composed of glasses with low silica contents and having the higher indexes of refraction generally gave higher initial reflectance values. Such structural defects as bubbles in these beads were evidently not of significant proportion to appreciably affect their reflex-reflection characteristics on initial application

Regardless of whatever effect the presence of bubbles or other structural defects may have on initial reflectance values, their presence cannot be discounted without full knowledge of their effect on the structural strength of the beads and its relationship in terms of durability under traffic wear It is obvious that crushing and breaking of the beads under impact of traffic will result in loss of reflectance and the order of this loss will be some function of the resistance of the beads to rupture The apparatus and procedure described previously provides a measure of the crushing strength. The rate of loading of 70 lb per min , specified in the procedure, was selected arbitrarily to best fit the apparatus. Rates of loading ranging from 28 to 280 lb. per min. did not appreciably alter the strength results This apparatus is admittedly massive for the small particle being tested and future refinement of test is to be anticipated Nevertheless, the need for weeding out structurally weak beads seems to be established on the basis of the results obtained on Bead E.

The gradations of the beads were similar with the exception of Bead E which was considerably coarser than the others This bead was evaluated in all tests by results obtained on the material submitted without regard to the effect of the coarse gradation. Bead C was slightly finer on the No. 30 and No. 50 sieves, which was probably not too significant in average evaluations. The gradation of Bead D is considered about the optimum for highway application. Such a gradation has enough larger beads for early reflectance, with diminishing sizes to become effective as the paint film wears away and the larger beads are lost. Earlier exploratory work (not reported) on gradations of 100 per cent passing the No. 40 sieve and 100 per cent passing the No. 70 sieve indicated better performance for the coarser gradation not only for early reflectance but for maintenance of reflectance.

Laboratory prepared glass panels appear to provide the best approach for evaluating initial reflectance of the beads Precise paint film thicknesses can be applied and fairly uniform bead coverage can be attained by means of the gravity flow motor propelled gear track dispenser designed for the investigation Besides being useful for initial reflectance, the beaded paints can be utilized for other tests, particularly atmospheric exposure. Such exposure proved to be a ready means of verifying the non-durable nature of the glass composition used in Bead A

In preparing beaded glass panels consideration must be given to optimum paint thickness and quantity of beads applied. It is obvious that thick paint films will tend to "drown" the beads whereas too heavy an application of beads will appreciably affect directional reflectance because of what might be termed "bead interference" Wet paint film thickness of 18 mils and bead application of 6 lb per gal. of paint seem to provide desirable conditions for comparative evaluation

A number of preliminary and exploratory laboratory tests were conducted, the data from which are not considered sufficiently extensive or significant to be reported These included impact tests of the beads, freezing and thawing of beaded stripes on glass panels, and various water, dilute acid and alkali solubility tests. Laboratory wear tests of the beaded stripes were not attempted because of the uncertainty of existing methods to provide valid correlation with service records

DISCUSSION OF FIELD DATA

Accelerated Tests

Transverse Lines, Route 50 Cole County—The data obtained from all field installations are necessarily affected by many factors and cannot be as conclusive as data obtained from laboratory studies where more precise control of procedures and equipment is possible Variations in reflectance measurements of field installations may be caused by non-uniformity of bead distribution and by presence of foreign materials on the lines Variations may also be caused by differences in rates of bead and paint application, initial bead retention, paint scaling and differential wear At some time during the tests, the effects of paint scaling and wear overshadow the performance of the beads themselves, and it becomes necessary to disregard subsequent results in order to make proper comparisons In other words, at some point differences in reflectance values are no longer significant in terms of bead performance alone However, the differences in reflectance which were obtained in these tests are considered to be sufficiently consistent and of such magnitude that some definite trends are indicated and that some significant evaluations can be made

The trends shown by the data from the accelerated tests on Route 50, Cole County, are as follows

Bead A produced an initial brightness higher than other beads used, which would be expected as the result of its high index of refraction, but its brightness consistently and rapidly decreased to relatively low values These beads became severely etched and bead loss was generally a prominent factor

Bead B consistently gave the lowest initial brightness values but it maintained these low values with considerably less loss, percentage-wise, than most other beads. Low reflectance values may be ascribed to milkiness and surface scoring caused during manufacture.

Beads C and D which seem to be closely parallel in reflective performance gave relatively high initial values and with a few exceptions maintained satisfactory values for longer periods than the other beads except Bead H In Sections 1 to 6 inclusive they consistently outranked the other beads In Section 8 (nozzle striper) they outranked all except Bead H although Bead E also gave approximately equivalent results between the wheel tracks. In Section 10, the lines in which Bead C was used failed to show satisfactory initial bead retention as previously noted and for this reason the results were disregarded Beads C and D show what would be considered in the opinion of the authors the best general average efficiency in reflectance of all the beads included in these sections with the possible exception of Bead H

Bead E ordinarily gave reflectance values of a relatively low order and in Sections 1 to 6 inclusive, lost reflectance at rates equal to or greater than the other beads. It generally was superior to Bead A in maintenance of reflectance In Section 7 this bead showed a severe decrease in reflectance while in Sections 8 and 10 it showed a consistent decrease in brightness in the wheel tracks but performed considerably better between the wheel tracks Its position may be attributed to the presence of bubbles which no doubt contribute to its low average crushing strength and the resultant greater loss from the lines under the impact of traffic.

Bead F used in Sections 1 to 6 inclusive performed similarly to Bead A although it did not have as high an initial reflectance. The beads did not become etched but some surface scoring was observed

Bead H included in Sections 7, 8 and 10 produced an extremely high initial reflectance and maintained its reflective values very well except in Section 10 in the wheel tracks, where it dropped to the values of Bead D. Thereafter values were not quite so high as those of Bead D. It appears that this bead should, despite its unorthodox composition give satisfactory results in service; however, the field data on which this present opinion is based are limited to these three installations and cannot be considered conclusive.

It will be observed that the chart for Section 10, between the wheel tracks, shows an unusual drop and recovery of reflectance for all beads at 6 and 10 days while in the wheel tracks there are no such corresponding results. Examination of these lines at 6 days with a 20× glass showed that all of the beads between the wheel tracks were covered with a very fine coating. It is believed that this coating resulted from spillage from trucks hauling cement or agricultural limestone. This coating had disappeared four days later.

Further study of the figures and tables will reveal several other apparent inconsistencies. For instance in Section 1, between the wheel tracks, the line in which Bead B was used read lower at 27 and 30 days than at 45, 55 and 83 days. Also in Section 2 in the wheel track the line in which Bead E was used read higher at 21 days than it did the time before and the time after. Possible explanations for such inconsistencies are that the bead application was not uniform and that slightly different areas were viewed, even though the meter was placed in practically the same positions; that the image lines were irregular and the balances difficult to ascertain and were judged different from earlier and later readings; that the beads had become coated or had been polished by traffic between readings and thus were different in reflecting qualities, or that the observer erred in his readings. It has been found that fresh oil droppings change values and that fine powdery coatings definitely affect the results.

Unaccelerated Tests

Route 66, St. Louis County—The data and figures reveal that initial reflectance values were essentially the same regardless of the bead used. The envelopment of the beads where the first lot of paint was used seemed to exert very definite control over the development of their reflective qualities because of the low grazing angle of the Hunter meter. This caused them all to fall within a limited range. Where the second lot of paint was used and there was a lower degree of envelopment there were greater differences in initial reflectance. As was the case with transverse lines on Route 50, at some time during the tests the reflectance values began to be influenced by considerations other than bead performance alone. For these sections, it appears that between the ages of 68 days and 125 days inherent differences between the north and south lines began to appear. By 125 days, these differences affected the comparisons as much as or more than the differences in the beads themselves. Therefore, it is considered that the data obtained at 68 days is the latest that can be logically considered in making strict comparisons of bead performance. At this age these sections disclose the following tendencies in the relative performance of the beads used.

Bead A gave lower reflectance values than every other bead with which it was used except in Sections 17 and 18 The deep envelopment in the paint film prevented the high initial reflectance exhibited in the transverse test lines These beads became badly etched at an early age Bead B quite consistently rated below other beads with which it was compared except Bead A in Sections 1 and 2. Bead C generally gave slightly lower values than Bead D but higher values than Beads A and E. Bead D gave higher values than any other bead. Bead E gave lower values than Beads C and D but higher values than Beads A and B.

On the basis of these data the beads could be rated in decreasing order of reflectance values as follows: D and C, E, B, A.

Route 40 Montgomery and Route 50 Pettis—The data for the unaccelerated tests where the lines were placed in the center of the lanes show that they generally maintained their reflective properties in a very satisfactory manner for the duration of the observations. Wear on lines on curves to the left and on hills that had been heavily cindered during the winter, and paint scaling, caused greater differences in reflectance than the beads themselves.

On Route 40, Pettis and Montgomery Counties, the lines in which Bead D was used gave higher initial values than the lines in which Beads C and G were used and those lines maintained that higher reflectance through the 64 days readings. At 144 days the differences had decreased and at 187 days average reflectance values were approximately the same for all beads No significant differences developed at later dates.

On Route 50, Pettis and Johnson Counties, reflectance values at 6 days were all approximately equal. At 72 days, lines in which Beads G and D were used were brighter than those in which Beads C and E were used At 191 and 246 days, the average reflectance values for Beads C, D and G were approximately equal while those for Bead E reflected greater bead loss and were slightly lower More paint scaling was evident on these sections than on Route 40, possibly the result of applying the lines during cold weather. Since normal wear was so slight, except on curves and cindered hills, sufficient time had not elapsed at the end of the observations to bring out the differences in the characteristics of the beads to any significant degree as was possible in other tests.

The reflectance values of these lines, particularly on Route 50, Pettis and Johnson Counties, were initially of a lower order than for the transverse lines and some of the center lines on Route 66, St. Louis County These values may be ascribed to the heavy envelopment of the beads by the paint film.

From the data and observations presented in the report the following conclusions and indications seem to be warranted:

CONCLUSIONS

1. Commercially available reflective beads vary considerably in chemical composition and physical characteristics and the differences are of such magnitude that differences in performance in beaded lines result

2 The effectiveness of beaded paint lines decreases at varying rates as a function of time and traffic volume.

3. The presence of foreign materials such as soils, sand and other granular materials on the pavement surface, reduces the service life of a beaded paint stripe.

4 Reflectorizing beads should be rated on the basis of a reflectance or performance curve which includes enough of the time element to permit evaluation of resistance to weathering and traffic, rather than on the basis of initial reflectance alone.

5. Loss of beads from the paint film is an important factor in the diminishing of reflectivity of a beaded line

6. Structural strength is a factor in bead loss.

7 Imperfections such as scoring, scratching, etching, pitting and milkiness contribute to lowering of reflective efficiency

8 Chemical stability of the beads is essential to maintenance of reflectance. Deteriorating agents may include moisture, acids, paint film constituents, and ice removal agents

9. Accelerated traffic tests, in the form of transverse lines, are suitable for evaluation of service behavior of reflectorizing beads.

10. The Hunter meter is a useable instrument for the measurement of the reflectance of beaded surfaces, its accuracy being limited by the relatively small field of observation.

INDICATIONS

1. Beads, graded from coarse to fine, seem to result in better maintenance of reflectance than beads of a single size.

2. Excessively coarse gradations seem to result in increased bead loss.

3. The presence of irregular particles tends to decrease reflectance.

4. Bubbles or seeds seem to contribute to lowering of structural strength and resistance to traffic impact and hence to reduction of reflectivity of beaded lines.

5. For the type of field application and binder used in Missouri, a film thickness of approximately 18 mils and a bead application of 5 to 6 lb. per gal. seem to be within the optimum range for maximum efficiency.

6. Changes in viscosity or other characteristics of the paint may affect the embedment and envelopment of the beads and thus affect the early reflectance and efficiency of the traffic lines.

7. The thicker paint films tend to reduce bead damage and loss.

8 With proper techniques, photographic methods may be used to record reflectance comparisons and the progressive deterioration of reflective lines

SUGGESTIONS FOR FURTHER STUDIES

It is thought that further work along the following lines would be productive of information which would assist in the preparation of proper specifications and in making the most efficient use of reflectorizing beads.

Development or improvement of equipment and procedures for:

1. Test for structural stability of glass beads.
2. Test for quantitative determination of non-spherical particles
3. Measurement of reflectance of larger areas than is possible with current equipment.
4. Measurement of the composite or average reflectance of a substantial length of line by a moving photometer or other device
5. Application of test lines so as to control thickness and uniformity more closely.
6. A laboratory test for accelerated weathering and traffic action which may be correlated with field service

Studies to determine:

1. The magnitude of reflectance necessary to provide sufficient visibility for traffic control
2. Optimum film thickness of binder
3. Optimum rate of bead application
4. Optimum gradation or sizes of beads
5. Effect of varying quantities of non-spherical particles
6. Effect of chemical composition on durability
7. Composition of paint for optimum retention of beads

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APPENDIX

SPECIFICATION

The preparation of a specification which will provide suitable glass beads and yet not be overly restrictive, becomes a rather complex problem because of several factors The characteristics which should be included are fairly well known but it is difficult to specify limits for these characteristics which will provide suitable materials for all conditions It must be realized that the life of the binder which is influenced by its quality and the amount of traffic wear, is a very important factor From an economical standpoint it would not seem desirable to pay a premium for superior glass beads that would have long outlived the stripe on which they were placed Yet, on the other hand, the beads should be of such quality as to maintain satisfactory reflectance during the life of the stripe.

The following provisions and characteristic limits are listed as possible bases for the development of future specifications for reflectorizing traffic marking paint

GENERAL

1 This specification is intended to cover glass beads for application on traffic paint for the production of a reflective surface to improve the night visibility of the paint film.

2. The beads shall be manufactured from glass of a composition designed to be highly resistant to traffic wear and to the effects of weathering

MATERIAL

The beads shall conform to the following requirements

1 The beads shall be spherical in shape, and shall not include more than 30 per cent of irregularly shaped particles. They shall be essentially free of sharp angular particles, and particles showing milkiness or surface scoring or scratching

2 *Gradation:* The beads shall meet the following gradation requirements·

U S Std Sieves No	Percent Passing
20	100
30	80–95
50	18–35
100	0–10
200	0–2

3. *Index of Refraction:* The beads when tested by the liquid immersion method at 25°C shall show an index of refraction within the range of 1 50 to 1 65.

4. *Crushing Strength·* When tested in compression at a loading rate of 70 lb per min, the average resistance to failure of 10 beads shall be not less than the following.

20–30 mesh size	40 lb.
30–40 mesh size	30 lb.

5 *Initial Reflectance·* When the beads are applied at a rate of 6 lb. per gal on binder which has been applied with a Boston-Bradley Adjustable Blade or similar device having the opening set at 18 mils, the resulting stripe, at the end of 24 hours drying, shall show a directional reflectance value of not less than 14 using the Hunter night visibility meter. The binder used shall be Missouri State Highway Department Standard White Traffic paint or paint of similar pigmentation and non-volatile content

6 *Chemical Stability* Beads which show any tendency toward decomposition, including surface etching, when exposed to atmospheric conditions, moisture, dilute acids or alkalies or paint film constituents, may, prior to acceptance, be required to demonstrate satisfactory reflectance behavior and maintenance under such tests as may be prescribed.