A COMPARATIVE STUDY OF THE USE OF PLASTIC AND GLASS BEADS IN PAVEMENT LANE MARKING

Thesis for degree of Master of Science

Michigan State College

Charles Richard Buckham

1951

This is to certify that the

thesis entitled

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CHARLES RICHARD BUCKHAM

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A COMPARATIVE STUDY OF THE USE OF

PLASTIC AND GLASS BEADS IN PAVEMENT LANE MARKING

By

Charles Richard Buckham

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CHAPTER I INTRODUCTION

FOREWORD

The scientific advancements made by man in the last few decades in developing pavement markings, has undoubtedly played a major role in reducing the number of accidents each year that occur on the American highways.

We have certainly come a long way in the struggle for better pavement marking in the last few years. Evidences of traffic regulation are apparent in the pages of Roman history and in the New World we find traces of traffic marking dating back to the fifth century in the land of the Incas. This marking consisted of the placing of colored stones in the center of the highway and prevented many a tribal squabble through a definite system of traffic regulation.

In the year 1911 Mr. Edward Hines, then County Road Commissioner of Wayne County, Michigan, first conceived the idea of using a painted center-line on pavements. Since this time, man has continually been improving the paints that are used for this purpose.

The Michigan State Highway Department, in the year 1939, in an attempt to provide excellent night time illumination as well as day time illumination, began experimenting with small glass spheres placed on wet marking paint, thus producing a reflectorized paint. With the aid of these glass beads 24 hour visibility is obtained. The use of such beads make the center-line appear nearly three times more visible at night than a plain painted center-line.

These beads range in size from 0.0165" to 0.0029" in diameter. The Michigan State Highway Department has divided glass beads, for use in pavement marking, into two groups--namely Type I and Type II. Type I bead is intended for application on the surface of traffic paint films. Type II bead is intended to be mixed in traffic paints. According to the Michigan State Highway Department Specifications for glass beads "Type I shall be capable of firm embedment in the pavement marking paint with the upper surfaces of the glass beads exposed. Type II shall display the required reflective properties after traffic has worn off the paint film sufficiently to expose the surface of the beads." Type I bead is placed on the surface of the paint for immediate reflectivity and Type II is placed in the paint for continued reflectivity. The Type II bead is not used generally today on Michigan highways. However, Type I is used on all center-line markings made today.

The author of this paper was searching for a Type II plastic bead which possibly might be more effective and more economical than is the glass bead.

The object of this thesis was to determine whether plastic beads might be more satisfactory and more economical, as a lane marking material, than glass beads.

THEORY OF REFLECTION

These spheres, Type I, are deposited evenly on a wet pigment binder (paint) and are held firmly by the paint as it dries. The beads reflect the light from a car's headlights back to the driver's eye; thereby making the center-line appear to be luminous. A ray of light from the vehicle's headlight enters the sphere and is immediately bent at an angle determined by the refractive index of the material. From here the light ray strikes the mirrored surface of the sphere which is partially embedded in the paint or penetrates and strikes the pigment beyond and is returned in a path parallel to the incident ray back to the driver's eye. This is sometimes known as "reflex" reflection. It should be noted that the light ray is returned to its source and not necessarily in the opposite direction at an angle equal to the angle of incidence which is true in specular or mirror reflection. In the case of a perfect sphere, specular reflection follows practically the same path as reflex reflection.

This reflected ray of light carries the color of the paint in which it is embedded back to the driver's eye; thereby making the center-line appear to be luminous or have the same hue as in the daytime.

When the light ray from the car's headlight enters the bead, it is concentrated to a point of great intensity at the back of the sphere. This bright point of light is then reflected back to its original source thereby, with the aid of thousands of such spheres, lighting up several hundred feet of center-line.

Inasmuch as the distance between the entering and reflected ray is but a fraction of the diameter of the glass sphere, which in turn may be as small as .002 inches, the two rays are for all practical purposes almost coincident.

Figure 1 shows the result of a light ray from a glass or mirrored surface and is know as "specular reflection".

Figure 2 illustrates "reflex reflection" and Figure 3 "specular reflection" with irregular particles.

In Figure 3 ray "S" is the result of specular reflection and ray "R" is reflex reflection. It should be noted that neither ray is returned upon a path parallel or close to the entering ray. These two rays are known as "wild" rays and serve no functional purpose in pavement marking. It is for this reason that true spheres are essential for better control of the returned rays.

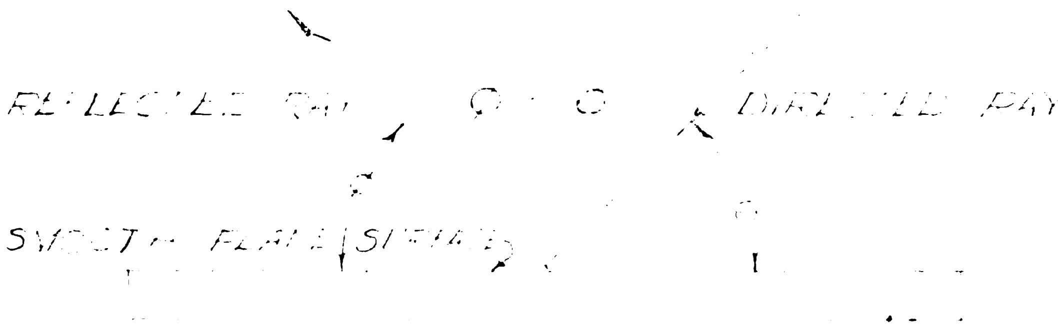


FIG. 1 SPECULAR REFLECTION

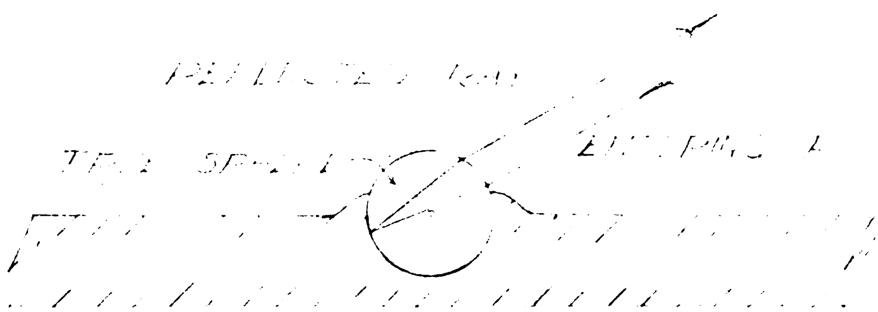


FIG. 2 REFLE[illegible] REFLEC[illegible]

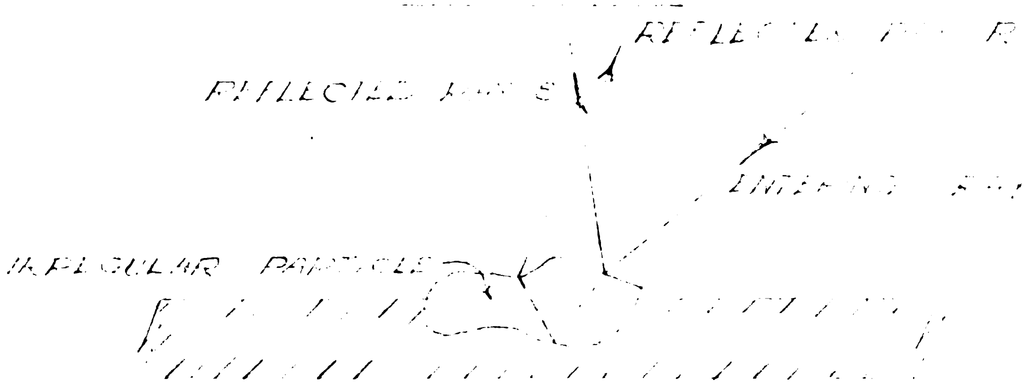


FIG. 3 SPECULAR REFLECTION
WITH IRREGULAR PARTICLES

REQUIREMENTS OF A SUITABLE MATERIAL

The beaded material used to increase the reflecting power of highway marking paints must meet very rigid requirements. One of the first requirements is obviously that the bead will not dissolve in the paint vehicle. Many plastics are attacked by certain organic substances which are used in the manufacturing of paints.

The degree of solubility is also a very important factor. It must be remembered that glass beads are soluble, to a slight extent, in water yet are used today as a reflecting medium.

The melting or flowing point of the bead material must be such that they will withstand summer temperature. It is not an uncommon occurrence to have pavement temperatures of 144°F at times during the summer months. Therefore, obviously beads which are to be used in this manner must be capable of withstanding temperatures of at least 144°F.

To be of value as a center-line marking material the beads must have an index of refraction of at least 1.50. An index of refraction greater than 1.50 is very desirable with a possible maximum of 1.90.

All beads must be perfectly spherical in shape. If the beads are not spherical in shape the light rays from the automobile's head lights will be dispersed in all directions and not returned to the driver's eye, which obviously is necessary if the material is to be of any value. Plastic beads are found to be much more perfectly shaped than are glass beads. Very few "out of rounds" are found when working with plastic beads.

If the beads are to withstand heavy trucks and cars rolling over them day after day they must have an average crushing strength of 7.5 kilograms for Type I and 2.5 kilograms for Type II. The test used to determine the average crushing strength of beads is explained on page 66.

The beads must not have enough color to impart a noticeable daytime hue to white marking paint.

The surface of the beads must be free from film mars, scratches and pits. When placed under a microscope (3X) at least 90 per cent of the beads (by count) must be free from excessive air inclusions, dark particles; spherical in shape and free from milkiness.[1]

To obtain a long and lasting life, various sizes of beads are used. The larger beads are lost to traffic first, followed by successively smaller sizes. It is for this reason that the beads must have a fairly wide range of diameters. Beads of uniform size would be of little value if used as a center-line marking material.

Another point that must be carefully considered is the difference in expansion rates of the paints and beads. Will the paint expand faster than the bead, thereby losing all bond between the bead and itself; or will the bead contract faster than the paint, thus being loosened and lost?

The specific gravity of the bead is also an important factor. Whether or not the bead will float or sink when applied to the paint medium is of prime importance. If the bead is too light it will never sink into the paint and thus the life of the bead will

[1] Michigan State Highway Specifications

be materially shortened as the top layer of paint is worn away.

When dealing with plastics, the possibility of the beads being attacked by gasoline and oil from passing cars must be carefully weighed and checked.

The reflectivity of the material, according to the Michigan State Highway Department 1951 Specifications for glass beads, must be at least 1.0 candle power per foot candle per square foot at 0° entrance angle. In other words the specific intensity must be equal to 1.0 $CP/FCxFT^2$. The procedure used to determine the reflectivity of beads is given on page 41.

To be of value as a center-line marking material the bead must meet all the above requirements. The author, after extensive searching for suitable plastics for this use, narrowed the field to two plastics—namely Methyl Methacrylate (Plexiglas) and Polystyrene (Styron). Plexiglas is made by the Rohm and Haas Chemical Company of Philadelphia, Pennsylvania, and Styron is manufactured by the Dow Chemical Company of Midland, Michigan. As a control for the tests run on these two plastics the author chose today's accepted material—glass beads. All major tests were run first on the glass beads to establish a means of control or comparison of the two "foreign" materials Styron and Plexiglas.

CHAPTER II GENERAL PROPERTIES

GRADATION

If proper film thickness is used, full reflective value of the line is not secured until it has been under traffic, and vehicular abrasion has uncovered spheres initially covered by the wet paint film. Depending entirely upon the amount and kind of traffic, this period may be a few days or it may be several months.

The spheres are graded in such a way as to provide constant reflectivity during the entire life of the highway marking.

Theoretically the paint film can wear to about .004 inches in thickness (enough to retain the smallest sphere of .009 inches diameter) and will still be reflective. A paint film of .004 inches is so thin that it can readily be seen through.[1]

Figure 4, page 11, shows a picture of the Plexiglas bead before any traffic of any kind has passed over it. Notice that none of the beads have been pried loose.

Figure 5, page 12, shows a photograph of Type I glass beads which have been subjected to several months wear by traffic at the intersection of M 25 and M 29 north of Mount Clemens. Notice how the larger beads have been pulled out by passing vehicles and how continued reflectivity is now dependent upon the smaller beads. As has been stated before, it is for this reason that a uniform gradation is very poor if the beads are to be used for center-line marking purposes.

The sieve analysis for Plexiglas, Polystyrene, and glass

[1] Prismo Bulletin 443, Prismo Glass Corporation.

beads are given in Tables I, II, and III respectively.

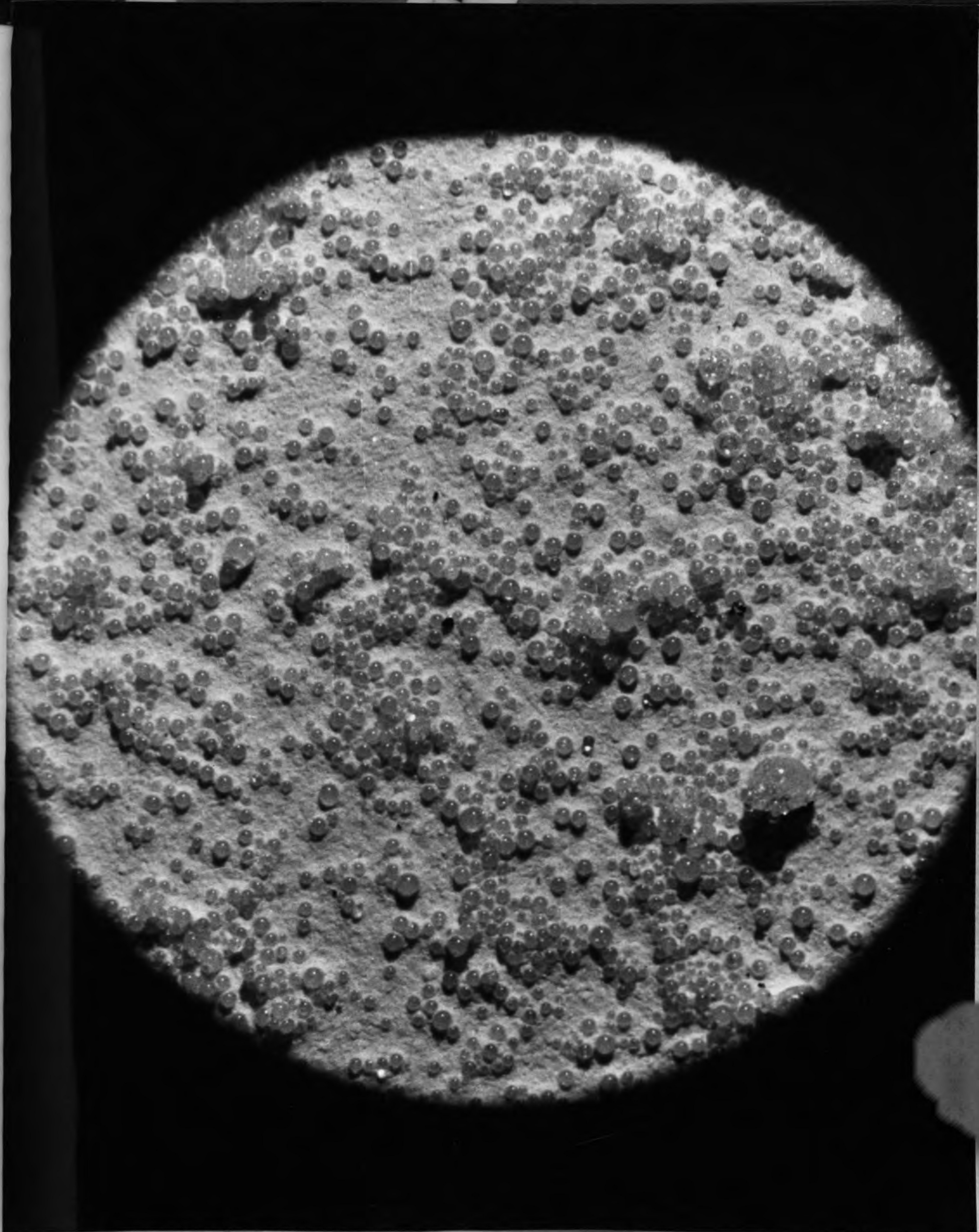


Fig. 4 Plexiglas Beads in White Paint

Magnified 10 Times

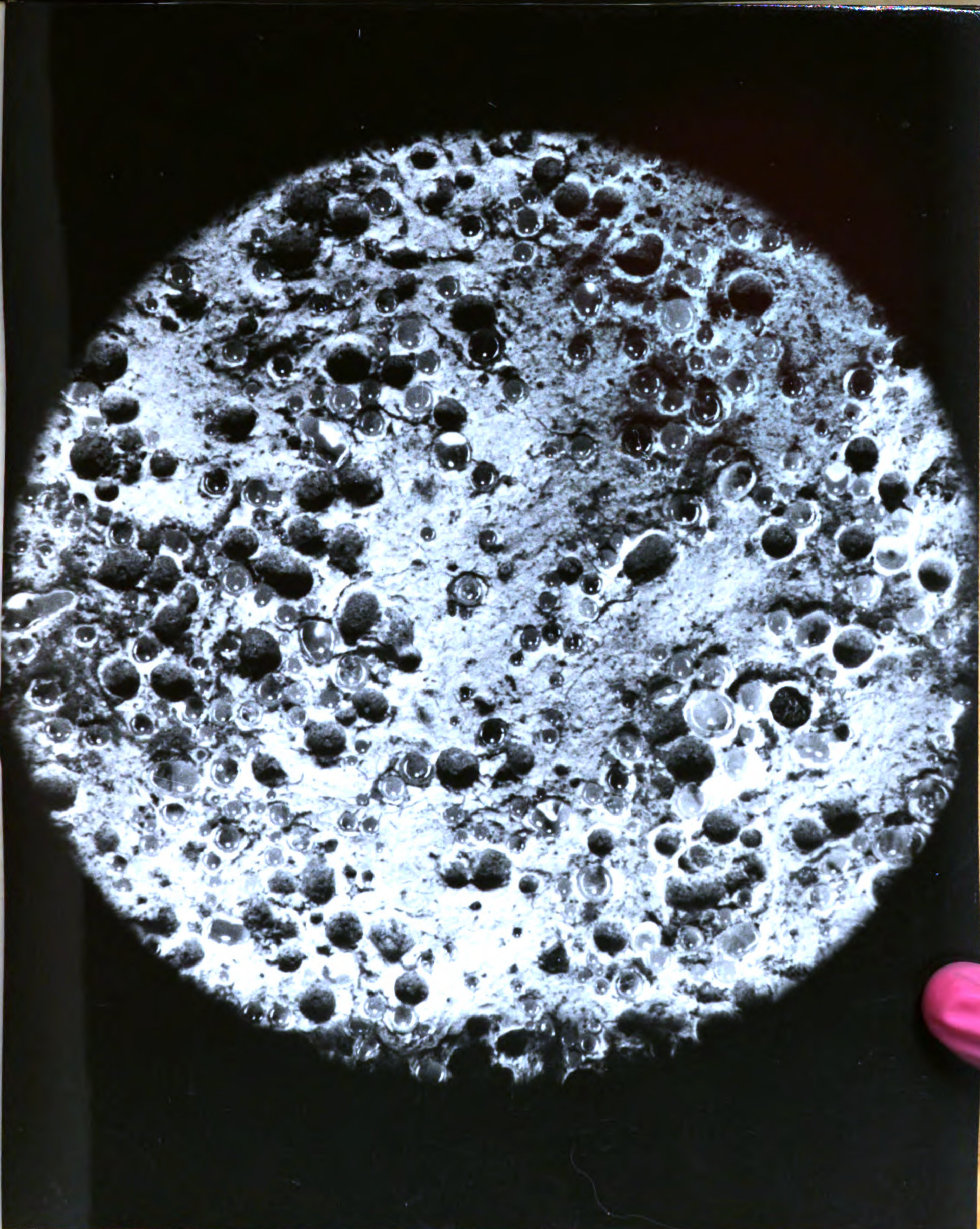


Fig. 5 Glass Beads in White Paint after several months use

Magnified 10 Times

TABLE I

Sieve Analysis of Plexiglas Beads

The total weight of beads used in sieves (10, 20, 30, 40) was 103.0. The total weight of beads used in sieves (60, 70, 80, 100, 140, 200) was 196.5. These two samples were obtained by using a sample splitter.

Sieve No.	Grams	% Retained	% Passing
10	0.0	0.0	100.0
20	0.1	0.1	99.9
30	0.4	0.5	99.5
40	0.9	1.4	98.6
60	22.5	11.5	88.5
70	40.0	32.4	67.6
80	117.0	92.0	8.0
100	10.0	97.0	3.0
140	5.0	99.5	0.5
200	0.7	100.0	0.0
Pan	0.2	100.0	0.0

TABLE II

Sieve Analysis of Polystyrene Beads

The total weight of beads used in this test was 120.9 grams—obtained by using a sample splitter; thereby insuring a representative sample.

Sieve No.	Grams	% Retained	% Passing
*20	0.4	0.3	99.7
*30	0.5	0.7	99.3
*40	1.9	2.3	97.7
50	13.9	13.8	86.2
60	19.4	29.9	70.1
70	30.9	55.4	44.6
80	32.2	82.1	17.9
100	10.1	90.4	9.6
200	10.9	99.4	0.6
Pan	0.7	100.0	0.0

* Clusters of smaller beads melted together.

TABLE III

Sieve Analysis of Cataphote Type I Beads

The total weight of beads used in this test was 559 grams—obtained by using a sample splitter; thereby insuring a representative sample.

Sieve No.	Grams	% Retained	% Passing
20	0	0.0	100.0
30	79	14.1	85.9
40	176	45.5	44.5
50	174	76.7	23.3
100	128	99.6	0.4
200	2	100.0	0.0
Pan	0		

COLOR

According to the specifications the beads must be colorless to the extent that they do not impart a noticeable daytime hue to white pavement marking paint.

Both the Plexiglas and Styron beads can best be described as to color by saying that they look exactly like salt or sugar grains. On the other hand, glass beads are slightly more transparent than either plastic bead. However, both Plexiglas and Styron are considered to be transparent. From the author's point of view the plastic beads meet the present Michigan State Highway Department Specifications as far as color is concerned. It must be remembered however, that neither plastic bead is as transparent as the glass bead.

IMPERFECTIONS

To be useful as a center-line marking material the bead shall contain not less than 90 per cent (by microscopic count) perfect spheres, free from film, scratches, pits, milkiness, dark particles, and excessive air inclusions. The surface of the spheres must be smooth and lustrous.

Approximately 1,000 beads were checked under a microscope for the above named imperfections. It was found that both plastic beads contained practically no misshaped or "out of round" beads. The author also discovered that both Styron and Plexiglas contained much less air inclusion per 1,000 beads than was found in glass beads. The results of the beads checked by the author are shown in Table IV.

The author would like to comment on the count made on the

Plexiglas beads. If any air bubbles at all were found in a bead it was immediately rejected as an imperfect bead. However, on both the Polystyrene and glass beads only excessive air was ruled as reason for rejection. It is for this reason that the Plexiglas bead shows a slightly higher imperfection rate than does the Polystyrene. Actually placing the three types of beads in decreasing order of perfection they would range (1) Plexiglas, (2) Polystyrene, and (3) glass.

The Polystyrene beads seemed to contain a greater number of beads with surface mars or scratches.

Another method of determining the number of imperfect beads is to place a representative sample under a microscope and take a picture of them. In this way the number of out of round beads and the number containing excessive air may readily be determined.

Figures 6, 7, 8 and 9 are four pictures which were used by the author to determine the number of imperfect beads. The first of the pictures, Figure 6, shows a rather poor sample of Minnesota Mining and Manufacturing Company beads. Figure 7 shows a fairly good sample of 3M beads. In Figure 8 is shown a picture of Plexiglas and in Figure 9 is a picture of the Polystyrene beads.

TABLE IV

Bead Imperfections

	Polystyrene		Flexiglas	
Trial	Total	Imperfect	Total	Imperfect
1	127	5	243	13
2	148	4	93	4
3	119	3	102	6
4	220	10	220	10
5	168	6	159	7
6	101	3	144	6
7	141	5	86	5
8	111	4	219	8
9	138	6	52	3
10	97	3	96	1
Total	1,379	49	1,414	63

% Imperfect =

$$\frac{49(100)}{1379} = 3.5\%$$

% Imperfect =

$$\frac{63(100)}{1414} = 4.5\%$$

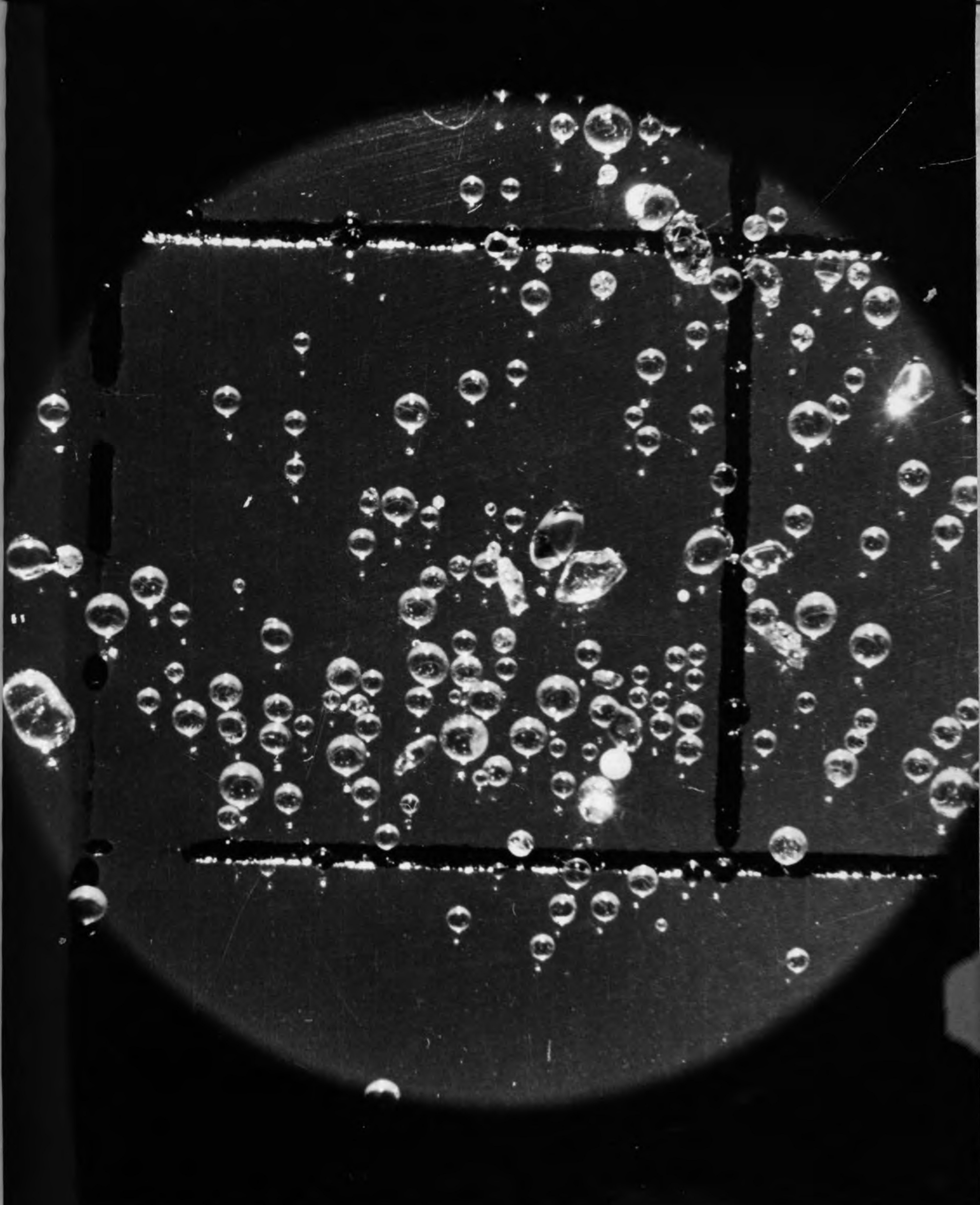


Fig. 6 3M Glass Beads

Magnified 10 Times

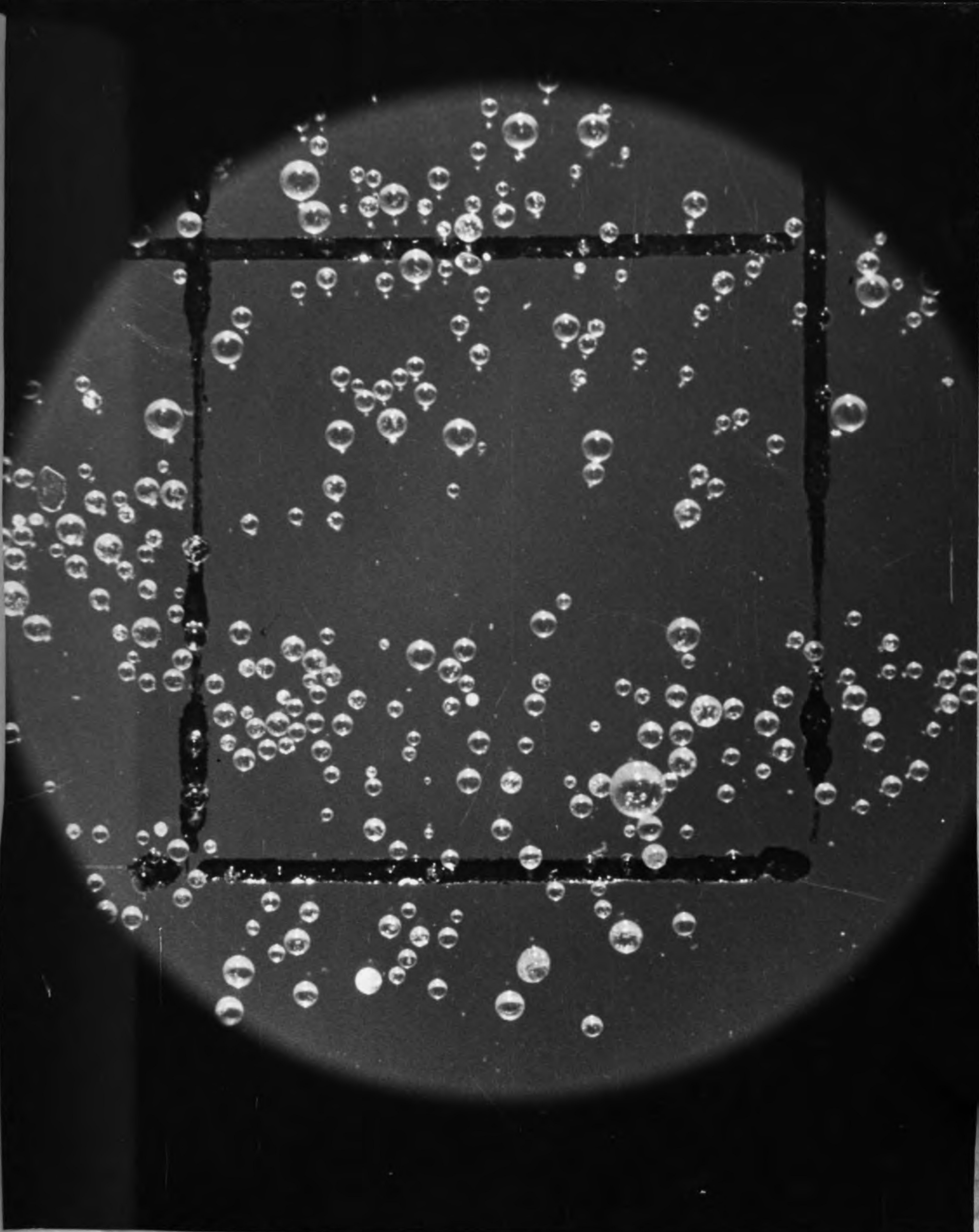


Fig. 7 Improved 3M Glass Beads

Magnified 10 Times

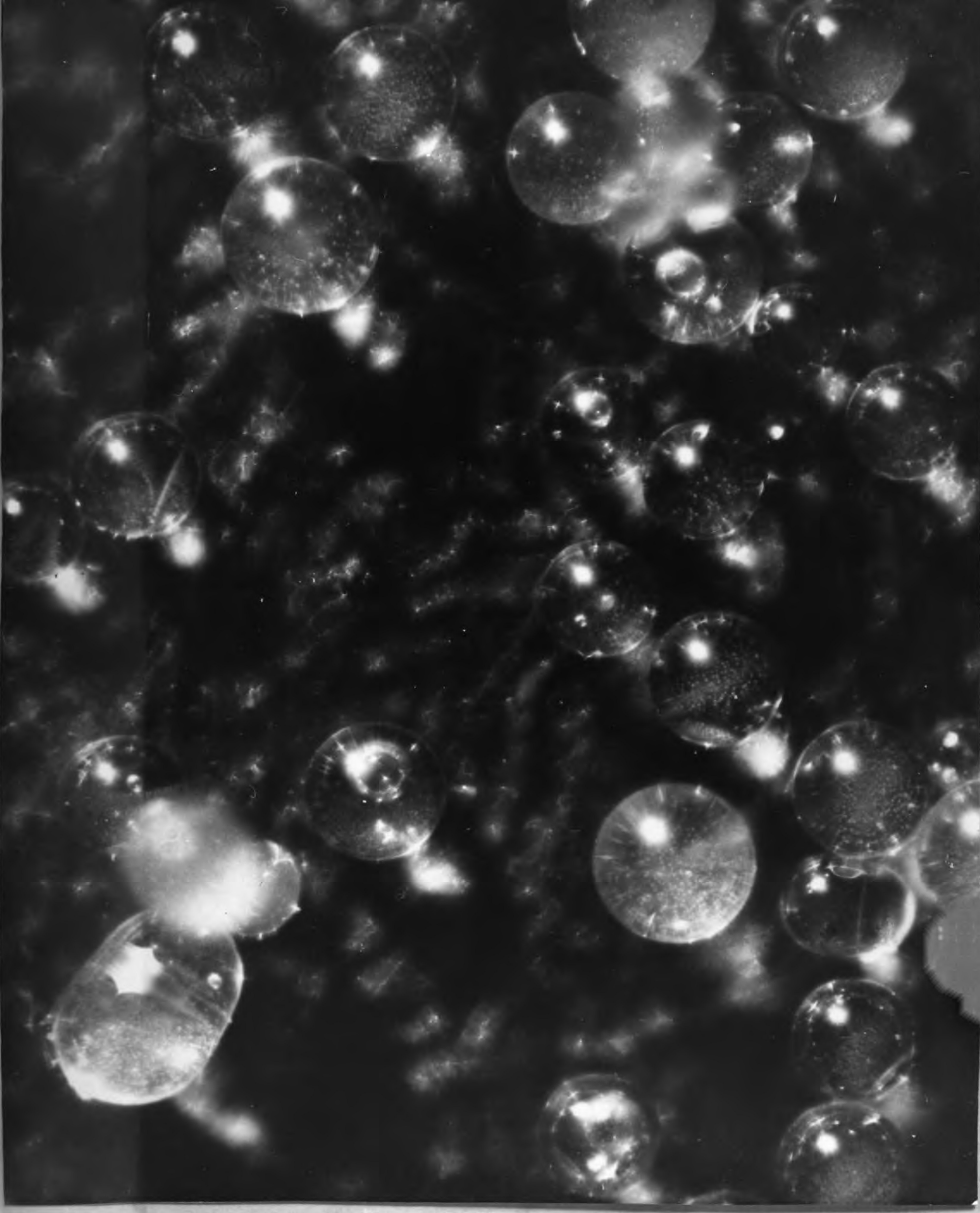


Fig. 8 Plexiglas Beads

Magnified 180 Times

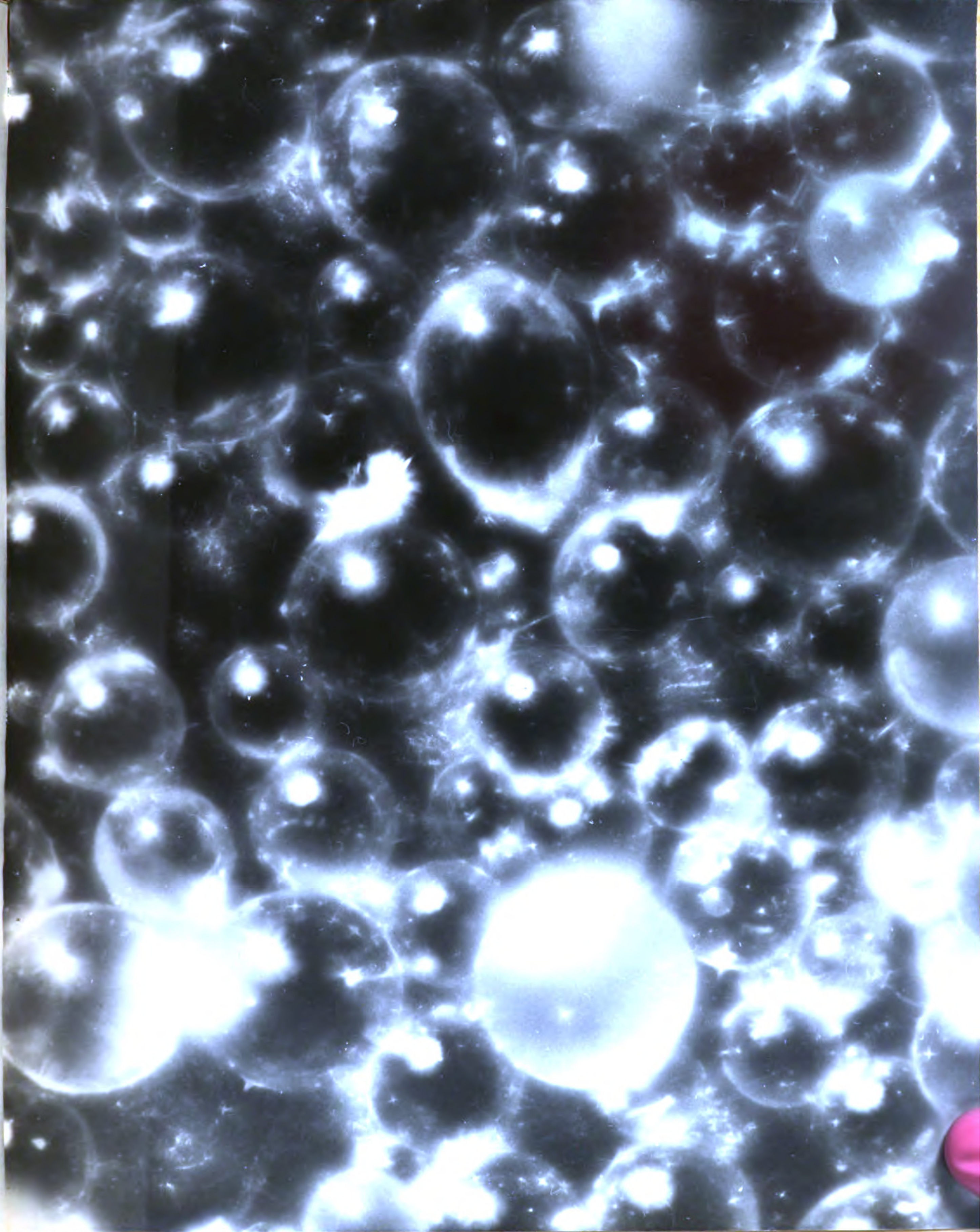


Fig. 9 Polystyrene Beads

Magnified 180 Times

EXCESSIVE AIR

Just what is "excessive air"? A test used to determine excessive air is given below. The specific gravity, using a pyonometer, is run on the whole beads as received from the factory. Next the beads, approximately 250 grams, are crushed in a ball mill using a load of 550 grams of nominally 3/4 inch flint pebbles.

Tumbling is continued for 4 hours. Approximately 10 grams of the powdered material passing a No. 325 sieve is used to run a new specific gravity.

The per cent of voids by volume was computed by the formula shown below.

$$\text{Voids in } \% = \frac{(\text{sp gr of Plexiglas} - \text{sp gr of whole bead})\ 100}{\text{sp gr of Plexiglas}}$$

The per cent voids must be less than 2%.

Another method of determining excessive air, is to place the beads in a liquid of the same index of refraction as the beads themselves and look at them under a microscope. Any air bubbles which might be entrapped in the bead will show up as black dots.

In Figures 10, 11 and 12 are three pictures of glass, Plexiglas, and Polystyrene beads placed in liquids of the same index of refraction as themselves.

Notice the difference between the number of black dots contained in the Minnesota Mining and Manufacturing Company beads and the number entrapped in the Polystyrene beads.

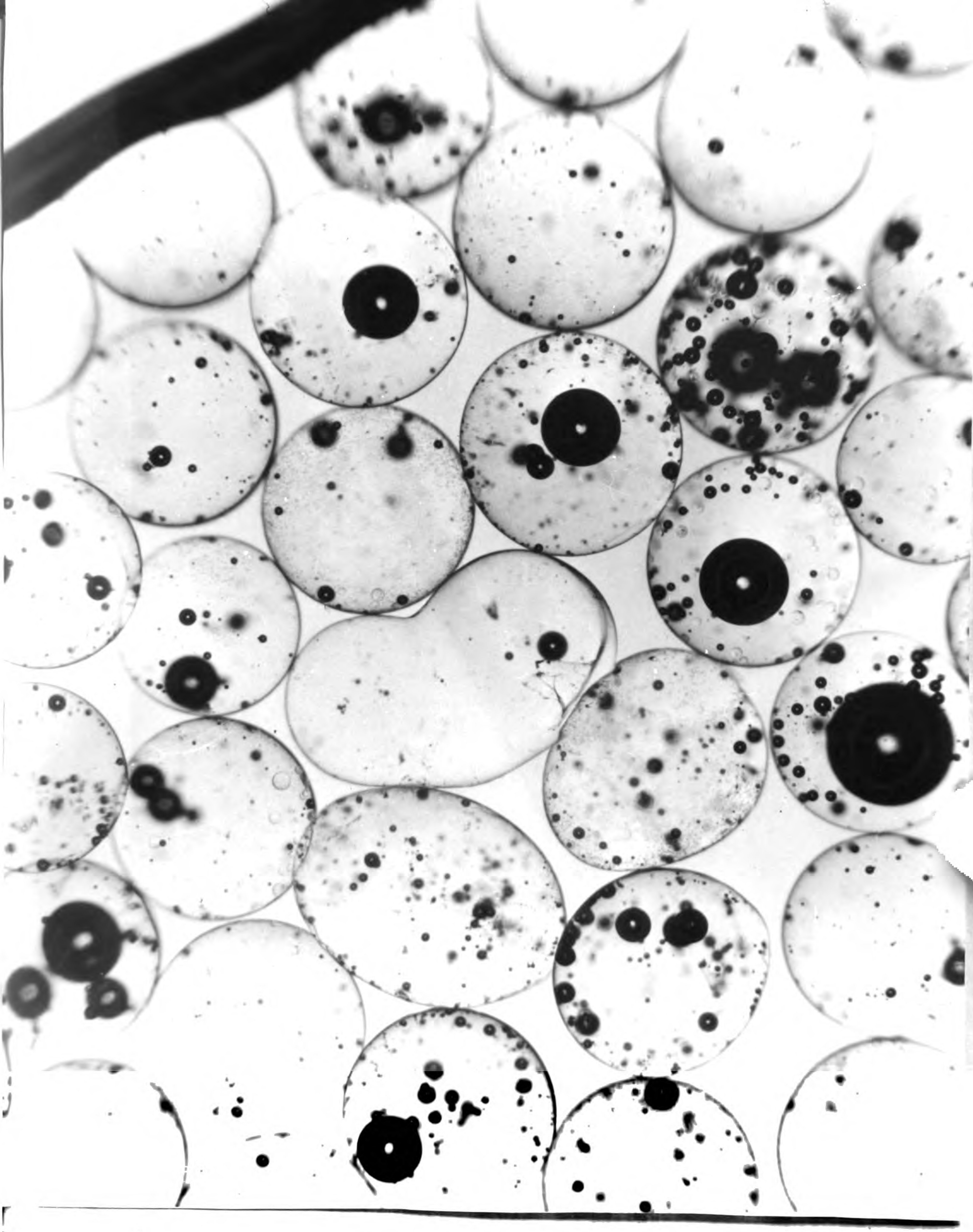


Fig. 10 3M Glass Beads in Benzene (n=1.5)

Magnified 85 Times

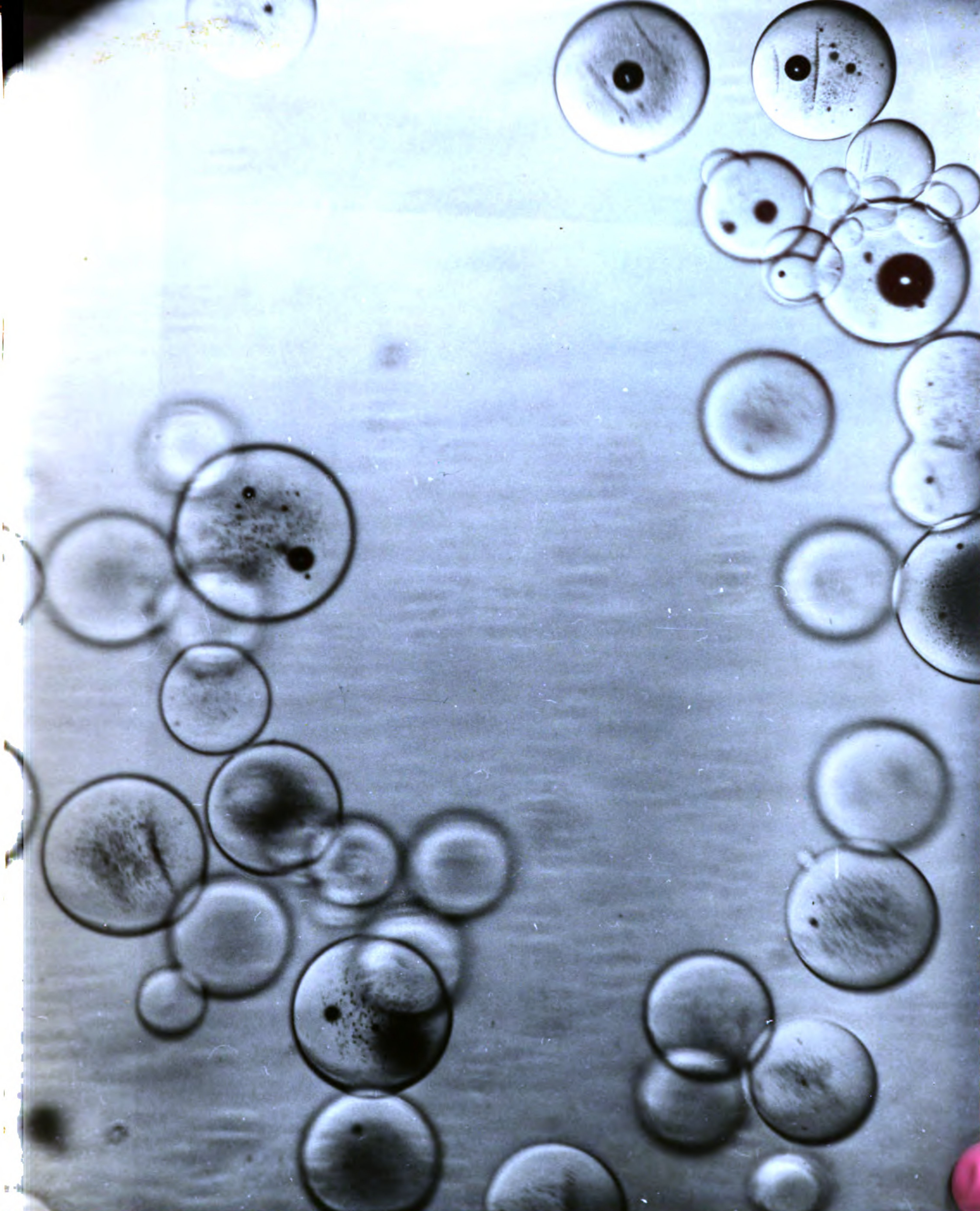


Fig. 11 Plexiglas Beads in Cedar Oil (n=1.51)

Magnified 180 Times

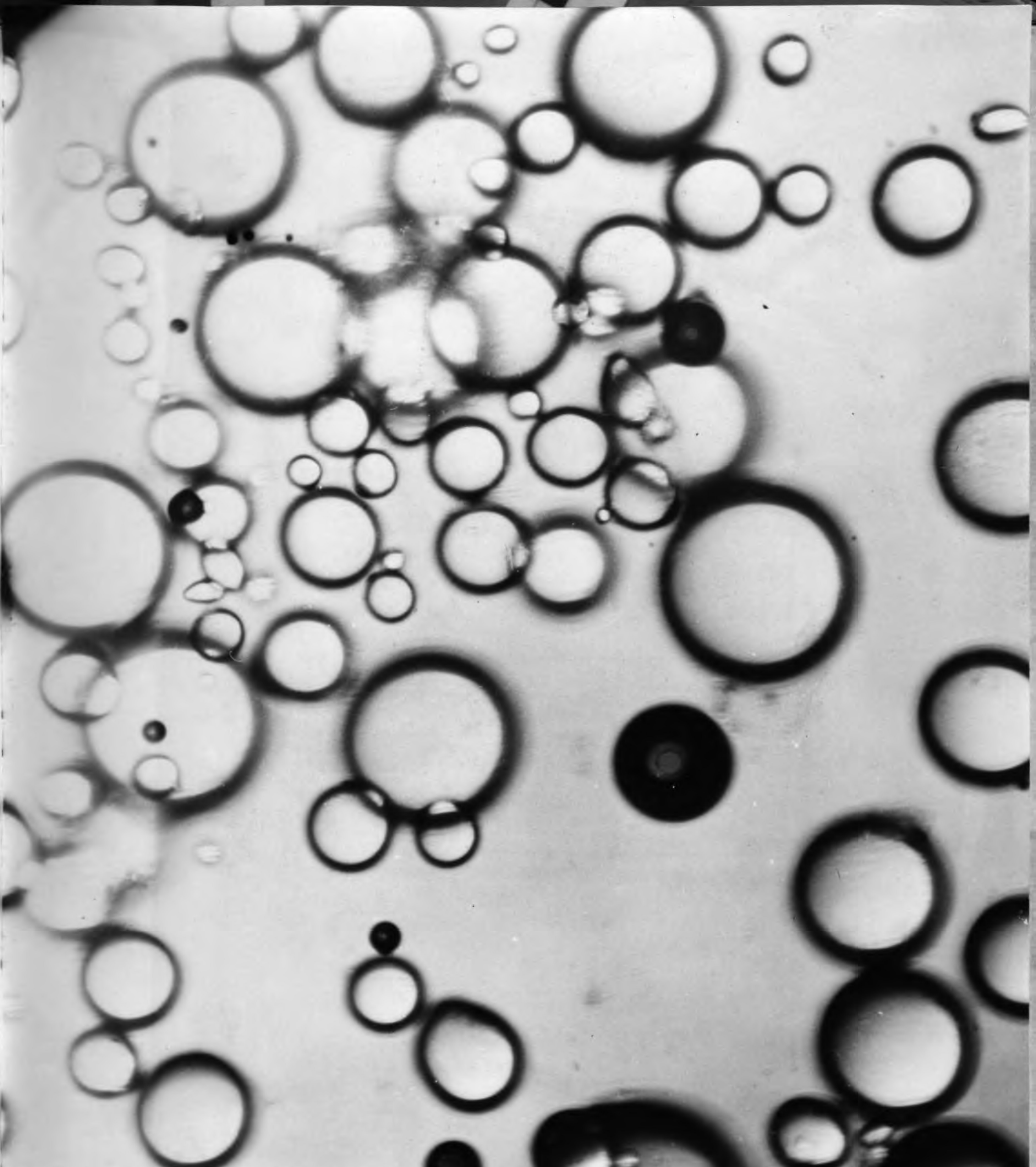


Fig. 12 Polystyrene Beads in Cedar Oil (n=1.51)

Magnified 180 Times

ODOR

Both Plexiglas beads and Styron beads have very peculiar odors. The Plexiglas beads can best be described as smelling something like witch-hazel. The Styron beads smell like an orange peeling that has just started to ferment. It should be stated however, that these odors are not very strong and therefore are not objectionable.

The presence of any odor would seem to indicate that there is some sort of chemical decomposition occuring in the beads.

EFFECT OF TEMPERATURE

A few grams of Plexiglas beads were placed in a container and boiled for one minute. The beads were immediately checked under a microscope and it was observed that they had begun to elongate. An increase in the amount of air bubbles present was also observed.

Boiling was continued for 15 minutes and the beads were again checked under the microscope. By this time the beads had disintegrated into fine thread-like pieces.

In the summertime it is not uncommon for pavement temperature to reach 144°F in Michigan. It is for this reason that the beads must stand up under temperatures of 144°F.

The heat distortion temperature of Plexiglas, using A.S.T.M. D-648-45 T test conditions and increaing the temperature $\frac{1}{2}$°C per minute with a load of 264 psi was found to be 62°C (144°F).[1]

[1]Rohm and Haas testing laboratory.

The distortion temperature of Styron is about 72°C. Therefore it is seen that both plastic beads are suitable for marking materials in Michigan as far as temperatures are concerned.

EFFECT OF WEATHERING

Plexiglas beads are superior to Styron beads in that they do not turn yellow as quickly with age. Plexiglas beads do turn yellow slightly upon being exposed to the weather for a long time. Styron beads however, have a greater tendency than do the Plexiglas. However, since the life expectancy of any one bead is limited, it is doubtful whether this slight yellowing would effect the reflectivity to a considerable extent.

EFFECT OF EXPANSION AND CONTRACTION

The expansion and contraction rates of the beads and the paints must be such that the bead is not loosened by a change in temperature. The test used by the author to determine the difference in expansion and contraction rates is given below.

A small panel, four by four inches, was made up containing both the paint and Plexiglas beads. This panel was allowed to dry thoroughly before testing started. The panel was then placed under a microscope and a few of the beads were loosened with a probe which served as a suitable instrument for removing individual beads. Next the panel was placed in an oven (144^{o}F) and allowed to remain there for 12 hours. It was then removed to a microscope and again individual beads were loosened with a probe. It was found that the beads were not loosened noticeably by an increase in temperature to 144^{o}F.

Next the panel was placed in a deep freeze and held at negative 2^{o}F for 12 hours. The panel was again removed to a microscope and beads pried loose with a probe. It was found that a temperature of negative 2^{o}F did make a slight difference in the ease with which the beads could be loosened. However, the difference was so small the author believes it would be practically negligible in the field.

CHEMICAL STABILITY

Many plastics that would make excellent center-line marking materials can not be used for this purpose because they are attacked by chemical solvents which are found in the paints. The material must be resistant to attack by gasoline, motor oil, or calcium chloride which are often found on the road surface. When calcium chloride comes in contact with water, it forms hydrochloric acid. Therefore the material must resist this acid.

One of the first steps taken by the author was to check the action of the paint vehicle on Plexiglas beads. Since about 50 per cent of the paint vehicle is composed of naphtha, the first test for chemical stability consisted of placing 5.60 grams of beads in a test tube and filling the remainder of the tube with naphtha. These beads were allowed to soak for two days. The tube was shaken at various intervals throughout the two day test. Next, the naphtha was very carefully evaporated with an electric fan leaving only the beads. No loss in weight of the beads was observed after the two days immersion in naphtha.

Four and one-half grams of beads were next placed in another test tube and enough paint vehicle, off the top of the 1950 yellow highway paint, added to fill the remainder of the tube. The beads were allowed to soak for 15 hours after which the vehicle was filtered off and the remaining beads rinsed clean with naphtha since it had previously been proven that naptha does not affect the beads.

The loss in weight due to 15 hours immersion in the paint vehicle was found to be negligible.

In still another test tube 6 grams of Plexiglas beads were covered with gasoline and shaken intermittently for 48 hours and again no loss of weight was observed. The Plexiglas bead is not attacked by gasoline.

However, it should be noted that it is not the loss in weight which is of interest but rather how the paint vehicle, gasoline, calcium chloride and naphtha affects the reflectivity of the beads.

COST

When considering materials to be used in such large quantities as is required for this type of work, the cost is naturally of prime importance.

The cost of glass beads is between 10 cents and 20 cents per pound. The cost of Plexiglas beads used by the author to conduct his tests is 70 cents per pound. The Polystyrene beads cost 89 cents per pound. This is a development price and is subject to review if a specific order comes in.

At first glance, the difference of 50 to 60 cents per pound between the glass and Plexiglas beads seems to disqualify immediately Plexiglas for this use. However, since the specific gravity of glass beads is between 2.65 and 2.89 and the specific gravity of Plexiglas is between 1.16 and 1.20, it is evident that better than twice as many Plexiglas beads per pound are obtained as glass beads. The specific gravity of Polystyrene is 1.05 as compared to 2.65 for the glass beads.

Let us assume the specific gravity of the glass beads to be 2.65 and the specific gravity of the Plexiglas beads to be 1.16. Let us also assume the price of glass beads to be 10 cents per pound and that of Plexiglas beads to be 70 cents per pound. Using these figures, it may easily be shown that the cost per pound to obtain the same number of beads (which is after all what we are interested in), is 10 cents for glass beads and 31 cents for Plexiglas.

$$70\left(\frac{1.16}{2.65}\right) = 0.31 \text{ cents}$$

Thus it is seen that Plexiglas beads cost approximately three times as much as do glass beads. By similar computation it was found that Polystyrene beads are three and one-half times as expensive as glass.

$$89\left(\frac{1.05}{2.65}\right) = 0.35 \text{ cents.}$$

However, it is believed by the author that increased production of the beads might reduce this difference in price.

Obviously, at today's (1951) prices it is far more economical to use glass beads than it is to use plastic beads of the types tested by the author.

CHAPTER III OPTICAL PROPERTIES

REFLECTIVITY TESTS

The prime interest is in reflectivity and not in loss of weight. It is for this reason that reflectivity panels were made using beads which had been subjected to five days of soaking in naphtha and in a saturated solution of calcium chloride. In the wintertime the beads would be exposed to a saturated solution of calcium chloride. It is for this reason that the author ran reflectivity tests on beads so exposed. It was found that the naphtha decreased the reflectivity to 0.8 as compared to 1.1 of the original bead. The saturated solution of calcium chloride decreased the specific intensity from 1.1 to 0.8.

DEFINITION OF TERMS USED IN REFLECTIVITY TESTS

Inverse Square Law:

The illumination of any surface varies inversely as the square of the distance from the source. (The illuminated surface must be perpendicular to the direction in which the light is travelling).

Illumination:

$$\text{Illumination} = \frac{\text{luminous intensity in candles}}{\text{square of distance from source}}$$

When the unit of length used is one foot, the unit of illumination is called the foot candle.

Specific Intensity:

Specific intensity is the unit of reflectivity and may be defined as the apparent candlepower of the reflector, per foot-candle of illumination falling on it, per unit area of reflecting surface.

Apparent Candlepower:

Apparent candlepower of a reflector is its luminous intensity expressed as the equivalent intensity of a point source producing an equal illumination at the same distance. Mathematically, it is the product of the illumination, in foot-candles, returned by the reflector to the point of measurement, and the square of the distance from that point to the reflector, in feet.

Angle of Incidence or Entrance Angle:

Angle of incidence or entrance angle is the angle between the direction at which light strikes the reflecting surface and a normal to the surface at that point.

Divergence Angle:

Divergence angle is the angle between the direction at which incident light strikes the reflecting surface and the direction from which the reflected light is seen or measured.

For long range reflectors, such as would be used for center-line markings, most of the reflected light must be conserved within a cone whose divergence angle is not more than 20 minutes. A divergence angle of 20 minutes corresponds to a distance of about 300 feet ahead of the vehicle.

APPARATUS[1]

The equipment used for the reflectivity tests as shown in Figure 13 consisted of (1) a goniometer, for supporting the specimen- (2) a bank of lights, for illuminating it--(3) a photoelectric cell and accessories for measuring the light reflected and (4) a separate foot-candle meter for measuring incident light.

The base of the goniometer is marked off in degrees. Left and right angles of incidence are established by turning the goniometer on its base. Right and left incidence angles of 0, 10, 20, and 30 degrees were used by the author in his tests for reflectivity.

The light source consisted of a bank of four equally spaced General Electric No. 4515 sealed beam lamps arranged in a group around a metal tube extending through the center of the cluster. Each lamp may be turned in any direction, as well as moved laterally toward or away from the axis of the metal tube. The angle of divergence is controlled by radial displacement of the lamps from the tube.

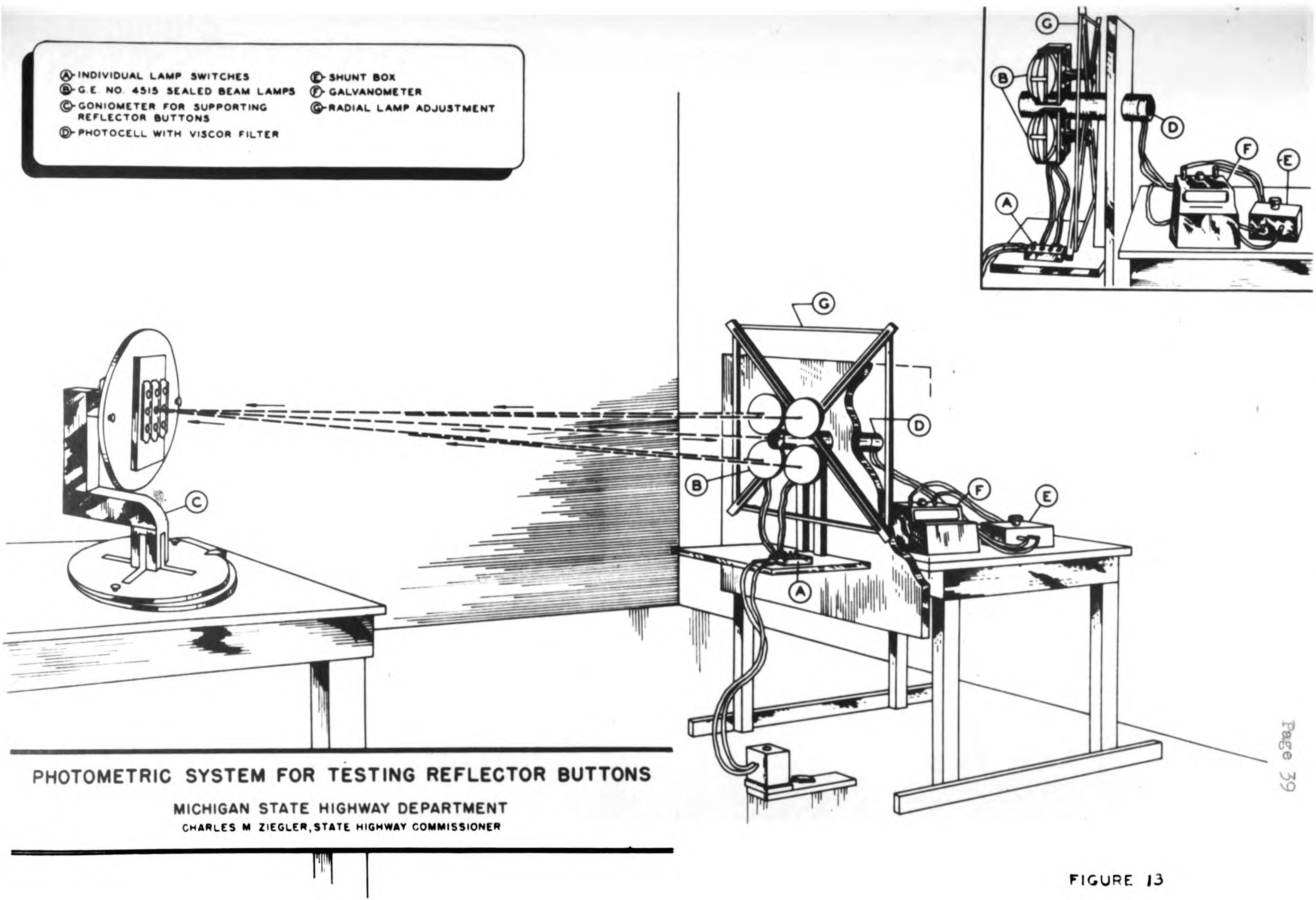
If the distance from the reflecting surface to the receptor photocell is exactly 50 feet and the center of each lamp exactly $3\frac{1}{2}$ inches from the center of the photocell, a divergence angle of 20 minutes is obtained. A divergence angle of 20 minutes is used for all Michigan State Highway Department routine testing. It was also used by the author. The lamps have individual switches and also a master foot switch.

[1]B. W. Pocock, C. C. Rhodes, Reflective Materials, Lansing, Michigan

The receptor photocell is clamped firmly against the rear end of the metal tube. The cell is a Weston Photronic Cell Model 594RR, equipped with a Weston Viscor filter, and is thus chromatically corrected to have a special response comparable to that of the average human eye.

The cell is connected to a measuring circuit containing a microammeter with an original sensitivity of approximately 0.03 of a microampere per millimeter division. A suitable shunt system is included to increase the range of the instrument by steps of approximately 10 to 1 and 50 to 1.

The incident light on the specimen is measured with a Weston Foot-Candle Meter, Model 614, containing a duplicate of the receptor photocell, also visually corrected.



PHOTOMETRIC SYSTEM FOR TESTING REFLECTOR BUTTONS

MICHIGAN STATE HIGHWAY DEPARTMENT

CHARLES M ZIEGLER, STATE HIGHWAY COMMISSIONER

FIGURE 13

PANELS FOR REFLECTIVITY TESTS

Three panels, each containing a paint stripe exactly four inches wide and eighteen inches long, were painted on metal plates which later were attached to the goniometer. Three stripes 4 x 18 inches gives a total painted area of 216 square inches or 1.5 square feet. It was found that an area of 1.5 square feet would return enough light to the photocell to produce sufficient sensitivity of the galvanometer to make accurate readings possible.

An under coat of .007 inches was first applied, (using a doctor blade), to each panel and allowed to thoroughly dry before the final coat of .011 inches was applied. This final coat was allowed to become slightly tacky before the beads were applied. Even distribution of the beads was obtained by using a salt shaker held six inches above the paint stripe.

The glass beads were applied at the rate of 6#/gal., the Plexiglas beads at the rate of 2.49#/gal. and Polystyrene beads at the rate of 2.20#/gal. As has previously been stated, the value of 6#/gal. was found by the Prismo Glass Corporation, after extensive research, to be the most economical rate of application. An increase in the application of the beads above 6#/gal. increases the reflectivity but not sufficiently to justify the increase in cost. The values of 2.49 and 2.20#/gal. were obtained as shown below.

$$6\#\left(\frac{1.19 \text{ sp gr Plexiglas}}{2.87 \text{ sp gr glass}}\right) = 2.49\#/\text{gal.}$$

$$6\#\left(\frac{1.05 \text{ sp gr Polystyrene}}{2.87 \text{ sp gr glass}}\right) = 2.20\#/\text{gal.}$$

PROCEDURE

The distance between the goniometer upon which the test panels are fastened and the photocell receptor was arbitrarily set at 50 feet. The 50 foot distance was measured exactly.

A black drop cloth was lowered behind the goniometer. All extraneous light was kept at a minimum, although the light in a dim corridor has very little effect upon the accuracy of the tests. The window shades on all windows leading into the corridor were drawn to keep the extraneous light at a minimum.

Next, the three test panels (total area equal to 1.5 square feet) were fastened on the goniometer with "C" clamps in such a way that the center of the middle panel was opposite the center of the goniometer face.

The lamps were now turned on, individually, and adjusted so that the sample was uniformly illuminated. Each lamp threw an oval shaped pattern on the test specimen. The object was to adjust each lamp individually until a uniform illumination was obtained. Uniformity of illumination is considered satisfactory only when the incident light, as measured at five points (four corners and the middle) by a foot-candle meter, varies by no more than plus or minus 5% the average value. The average illumination in foot-candles was recorded as the total incident light.

Next the ambient incident light, which is the illumination from the hall falling on the sample is measured with a foot-candle meter and is subtracted from the total incident light. The difference between the total incident light and ambient incident light is known as the incident light.

The total reflected light returned to the receptor photocell is now measured by means of a galvanometer. The test specimens are now covered with a black sheet and the reflected light (using all four lamps) again recorded. This value, which includes all stray light entering the tube from other sources, is know as the basic reflected light. The actual reflected light from the four lamps shining on the test specimen is then equal to the total reflected light minus the basic reflected light.

The reason the author used an area equal to one and one-half square feet of beaded surface was to provide sufficient reflecting surface area for adequate galvanometer response.

TEST RESULTS

The specific intensity test results are recorded in Tables V to XIX.

The actual galvanometer readings (Column 4) must first be converted to equivalent illumination in foot-candles (Column 5).* The reflected light in foot-candles is now converted to apparent candle-power of the reflector (Column 6) by multiplying by the square of the distance (50 feet) or 2500. This is simply an application of the inverse square law. The specific intensity (Column 7) is found by dividing the apparent candle-power by the incident light and again by the area of the reflecting surface.

Figures 14—18 show a graphical representation of the specific intensity test results.

* With the shunt used by the author, 40.27 scale divisions on the galvanometer are equal to one foot-candle. Therefore to change galvanometer readings to foot-candle merely divide by 40.27.

TABLE V

Plexiglas Beads

Rate of Application = 2.49#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	App. C.P.	$C.P./FCxFT^2$
0	1.4	3.8 3.7	2.35	.0584	146	1.1
10L		3.7	2.30	.0571	143	1.1
R		3.7				
20L		3.7	2.30	.0571	143	1.1
R		3.7				
30L		3.5	2.20	.0546	137	1.1
R		3.7				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \begin{matrix}89\\90\end{matrix}\ 102 \quad \begin{matrix}80\\86\end{matrix} - 3.5 = 85.9$$

Area = 1.5 sq. ft.

F.C. (Area) = 85.9(1.5) = 128.9

TABLE VII

Plexiglas Beads Passing A #70 And Retained On A #80 Sieve

Rate of Application = 2.49#/Gal.

Area: 3 $\left(\begin{matrix}4'' \times 18'' \\ \text{Panels}\end{matrix}\right)$ = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
0	1.3	2.9	1.6	.03973	99.3	0.75
		2.9				
10L		2.9	1.6	.03973	99.3	0.75
R		2.9				
20L		2.8	1.5	.03725	93.3	0.71
R		2.8				
30L		2.8	1.5	.03725	93.3	0.71
R		2.7				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{88}{82}\,106 \quad \frac{88}{90} - 3 = 87.8$$

Area = 1.5 sq. ft.

F.C. (Area) = 87.8(1.5) = 131.7

TABLE IX

Plexiglas Beads After Five Day Naphtha Bath

Rate of Application = 2.49#/Gal.

Area: 3 $\left(\frac{4'' \times 18''}{\text{Panels}}\right)$ = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid.. F.C.	APP. C.P.	C.P./FCxFT^2
	1.2	2.7	1.5	.0372	93.00	0.77
0		2.7				
10L		2.7	1.5	.0372	93.0	0.77
R		2.7				
20L		2.4	1.2	.0298	74.5	0.61
R		2.4				
30L		2.3	1.1	.0273	68.3	0.56
R		2.3				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \begin{matrix}84\\85\end{matrix}\ 93 \quad \begin{matrix}78\\80\end{matrix} - 3 = 81.0$$

Area = 1.5 sq. ft.

F.C. (Area) = 81.0(1.5) = 121.5

TABLE X

Plexiglas Beads After Five Day Gasoline Bath

Rate of Application = 2.49#/Gal.

Area: 3 ($\frac{4" \times 18"}{\text{Panels}}$) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FC×FT^2
0	1.7	3.2	1.5	.0372	93.0	0.8
		3.2				
10L		3.2	1.5	.0372	93.0	0.8
R		3.2				
20L		3.0	1.3	.0323	80.8	0.7
R		3.0				
30L		3.0	1.3	.0323	80.8	0.7
R		3.0				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{84}{72}\,100 \quad \frac{80}{84} - 2 = 82$$

Area = 1.5 sq. ft.

F.C. (Area) = 82(1.5) = 123

TABLE XI

Plexiglas After Five Day Calcium Chloride Bath

Rate of Application = 2.49#/Gal.

Area: 3 $\left(\frac{4'' \times 18''}{\text{Panels}}\right)$ = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
0	1.7	3.3	1.6	.0397	99.3	0.8
		3.3				
10L		3.3	1.5	.0372	93.0	0.7
R		3.1				
20L		3.1	1.4	.0348	87.0	0.6
R		3.1				
30L		3.0	1.3	.0323	80.1	0.6
R		3.0				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{82}{76}\ 100 \quad \frac{80}{86} - 1.5 = 83.3$$

Area = 1.5 sq. ft.

F.C. (Area) = 83.3(1.5) = 124.95

TABLE XII

Red Polystyrene Beads

Rate of Application = 2.2#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
		2.0				
0	1.0	1.9	0.95	.0208	52.00	0.5
10L		1.8	0.90	.0197	49.25	0.4
R		2.0				
20L		1.8	0.85	.0186	46.50	0.4
R		1.9				
30L		1.7	0.75	.0165	41.25	0.4
R		1.8				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{74}{72}\ 84\ \frac{78}{79} - 2 = 75.4$$

Area = 1.5 sq. ft.

F.C. (Area) = 75.4(1.5) = 113.1

TABLE XII

Red Polystyrene Beads

Rate of Application = 2.2#/Gal.

Area: 3 ($\frac{4" \times 18"}{\text{Panels}}$) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
		2.0				
0	1.0	1.9	0.95	.0208	52.00	0.5
10L		1.8	0.90	.0197	49.25	0.4
R		2.0				
20L		1.8	0.85	.0186	46.50	0.4
R		1.9				
30L		1.7	0.75	.0165	41.25	0.4
R		1.8				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \begin{matrix}74\\72\end{matrix}\ 84\ \begin{matrix}78\\79\end{matrix} - 2 = 75.4$$

Area = 1.5 sq. ft.

F.C. (Area) = 75.4(1.5) = 113.1

TABLE XII-A

Orange Polystyrene Beads

Rate of Application = 2.2#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
		3.0				
0	1.0	3.2	2.1	.0461	115.3	1.1
10L		3.2	2.1	.0461	115.3	1.1
R		3.0				
20L		3.0	1.9	.0417	104.3	1.0
R		2.8				
30L		2.9	1.8	.0395	98.8	0.9
R		2.7				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \begin{matrix}70\\70\end{matrix} \quad 80 \quad \begin{matrix}78\\78\end{matrix} - 3 = 72.2$$

Area = 1.5 sq. ft.

F.C. (Area) = 72.2(1.5) = 108.3

TABLE XIII

Polystyrene

Rate of Application = 2.20#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
0	1.3	3.9	2.7	.06705	167.8	1.28
		4.0				
10L		3.9	2.6	.06456	161.5	1.23
R		3.9				
20L		3.8	2.5	.06208	155.3	1.18
R		3.8				
30L		3.6	2.2	.05463	136.5	1.04
R		3.4				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{88}{84}\ 106 \quad \frac{84}{90} - 3 = 87.4$$

Area = 1.5 sq. ft.

F.C. (Area) = 87.4(1.5) = 131.1

TABLE XIII-A

Polystyrene

Rate of Application = 6#/Gal. (approx. saturated)

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
		5.0				
0	1.2	5.1	3.85	0.096	240.0	1.90
10L		5.1	3.85	0.096	240.0	1.90
R		5.0				
20L		5.0	3.8	0.095	237.5	1.88
R		5.0				
30L		5.0	3.75	0.094	235.0	1.86
R		4.9				
40L		5.0	3.7	0.093	232.5	1.84
R		4.8				
50L		4.7	3.3	0.083	207.5	1.64
R		4.3				
60L		3.5	2.2	0.055	137.5	1.09
R		3.3				
75L		1.2	0.3	0.008	20.0	0.16
R		1.8				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$FC = \frac{77}{78}\ 84 \quad \frac{74}{78} - 4 = 84.2$

Area = 1.5 sq. ft.

F.C.(Area) = 84.2(1.5) = 126.30

TABLE XIV

Polystyrene Beads After Five Day Naphtha Bath

Rate of Application = 2.20#/Gal.

Area: 3 $\left(\begin{matrix}4'' \times 18'' \\ \text{Panels}\end{matrix}\right)$ = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
	1.2	3.0	1.8	.0447	111.75	0.94
0		3.0				
10L		2.9	1.7	.0422	105.50	0.89
R		2.9				
20L		2.8	1.6	.0397	99.25	0.83
R		2.8				
30L		2.8	1.55	.0385	96.25	0.81
R		2.7				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \begin{matrix}83\\83\end{matrix}\ 92\quad \begin{matrix}75\\79\end{matrix} - 3 = 79.4$$

Area = 1.5 sq. ft.

F.C. (Area) = 79.4(1.5) = 119.1

TABLE XV

Polystyrene After Five Day Gasoline Bath

Rate of Application = 2.20#/Gal.

Area: 3 $\left(\begin{smallmatrix}4" \times 18" \\ \text{Panels}\end{smallmatrix}\right)$ = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	C.P./FCxFT^2
0	1.7	4.3	2.6	.0646	161.5	1.2
		4.3				
10L		4.3	2.6	.0646	161.5	1.2
R		4.3				
20L		4.1	2.4	.0596	149.0	1.1
R		4.1				
30L		3.9	2.2	.0546	136.5	1.1
R		3.9				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{84}{82}\ 103 \quad \frac{83}{88} - 1.5 = 86.5$$

Area = 1.5 sq. ft.

F.C. (Area) = 86.5(1.5) = 129.75

TABLE XVI

Polystyrene After Five Day Calcium Chloride Bath

Rate of Application = 2.20#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	APP. C.P.	$C.P./FC \times FT^2$
0	1.7	3.7	2.0	.0497	124.3	1.0
		3.7				
10L		3.6	1.9	.0472	118.0	0.9
R		3.6				
20L		3.4	1.7	.0422	105.5	0.8
R		3.4				
30L		3.3	1.6	.0397	99.3	0.8
R		3.3				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{84}{80}\ 100 \quad \frac{80}{85} - 2 = 83.8$$

Area = 1.5 sq. ft.

F.C. (Area) = 83.8(1.5) = 125.7

TABLE XVI

Polystyrene After Five Day Calcium Chloride Bath

Rate of Application = 2.20#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid. F.C.	App. C.P.	C.P./FCxFT^2
0	1.7	3.7	2.0	.0497	124.3	1.0
		3.7				
10L		3.6	1.9	.0472	118.0	0.9
R		3.6				
20L		3.4	1.7	.0422	105.5	0.8
R		3.4				
30L		3.3	1.6	.0397	99.3	0.8
R		3.3				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{84}{80}\,100\quad\frac{80}{85} - 2 = 83.8$$

Area = 1.5 sq. ft.

F.C. (Area) = 83.8(1.5) = 125.7

TABLE XVII

Cataphote Type I Glass Beads

Rate of Application = 6#/Gal.

Area: 3 (4" x 18" Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid F.C.	APP. C.P.	C.P./FCxFT^2
0	1.3	4.2 4.3	2.95	.0733	183.3	1.4
10L		4.2	2.85	.0708	177.0	1.3
R		4.1				
20L		4.0	2.7	.0670	167.5	1.3
R		4.0				
30L		4.0	2.7	.0670	167.5	1.3
R		4.0				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{86}{89} \quad 101 \quad \frac{81}{89} - 1 = 89.2$$

Area = 1.5 sq ft.

F.C. (Area) = 89.2(1.5) = 133.8

TABLE XVIII

Cataphote Type I Glass Beads
(90 Hour Reflux)

Rate of Application = 6#/Gal.

Area: 3 ($4'' \times 18''$ Panels) = 216 sq. in. = 1.5 sq ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid F.C.	APP. C.P.	C.P./FCxFT^2
		4.1				
0	1.3	4.2	2.85	.0708	177.0	1.3
10L		4.2	2.80	.0695	173.8	1.3
R		4.0				
20L		4.1	2.65	.0658	164.5	1.2
R		3.8				
30L		4.2	2.65	.0658	164.5	1.2
R		3.7				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \frac{90}{90} \quad 106 \quad \frac{86}{87} - 3 = 88.8$$

Area = 1.5 sq. ft.

F.C. (Area) = 88.8(1.5) = 133.2

TABLE XIX

White 1951 Highway Paint

Area: 3 ($4" \times 18"$ Panels) = 216 sq. in. = 1.5 sq. ft.

Entrance Angle	Scale Divisions Basic	Total	Actual	Ibid F.C.	APP. C.P.	C.P./$FC \times FT^2$
		2.3				
0	1.2	2.3	1.15	.0286	71.5	0.6
10L		2.3	1.15	.0286	71.5	0.6
R		2.3				
20L		2.2	1.05	.0261	65.3	0.5
R		2.2				
30L		2.0	0.85	.0211	52.8	0.4
R		2.0				

Shunt Box Setting: 40.27 Scale Divisions/F.C.

$$FC = \begin{matrix}87\\87\end{matrix} \quad 99 \quad \begin{matrix}79\\82\end{matrix} - 1 = 85.8$$

Area = 1.5 sq. ft.

F.C. (Area) = 85.8(1.5) = 128.7

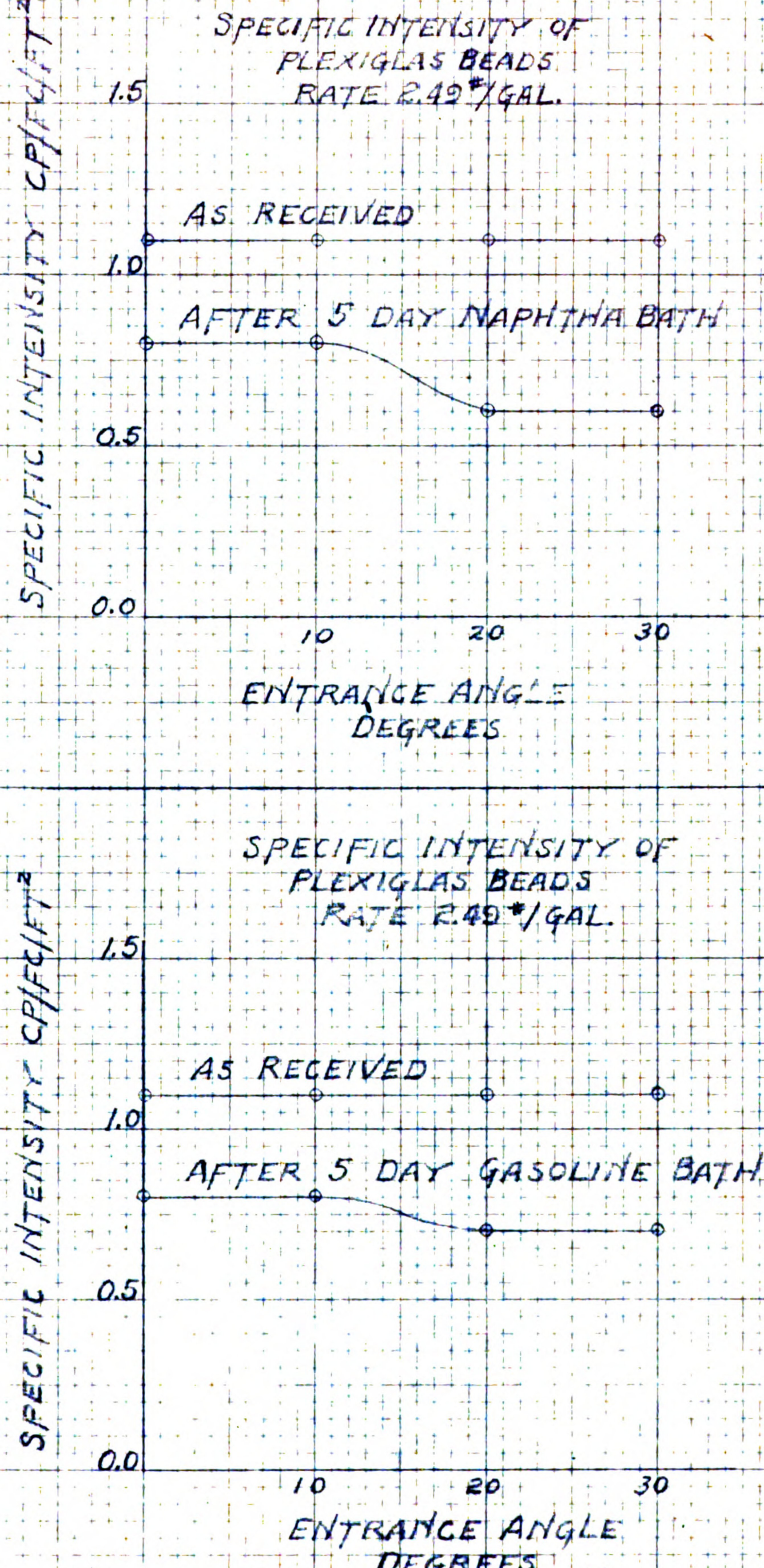

SPECIFIC INTENSITY OF
PLEXIGLAS BEADS
RATE 2.49#/GAL.
SPECIFIC INTENSITY CP/FC/FT²
1.5
1.0
0.5
0.0
AS RECEIVED
AFTER 5 DAY NAPHTHA BATH
10
20
30
ENTRANCE ANGLE
DEGREES
SPECIFIC INTENSITY OF
PLEXIGLAS BEADS
RATE 2.49#/GAL.
SPECIFIC INTENSITY CP/FC/FT²
1.5
1.0
0.5
0.0
AS RECEIVED
AFTER 5 DAY GASOLINE BATH
10
20
30
ENTRANCE ANGLE
DEGREES

FIG. 14

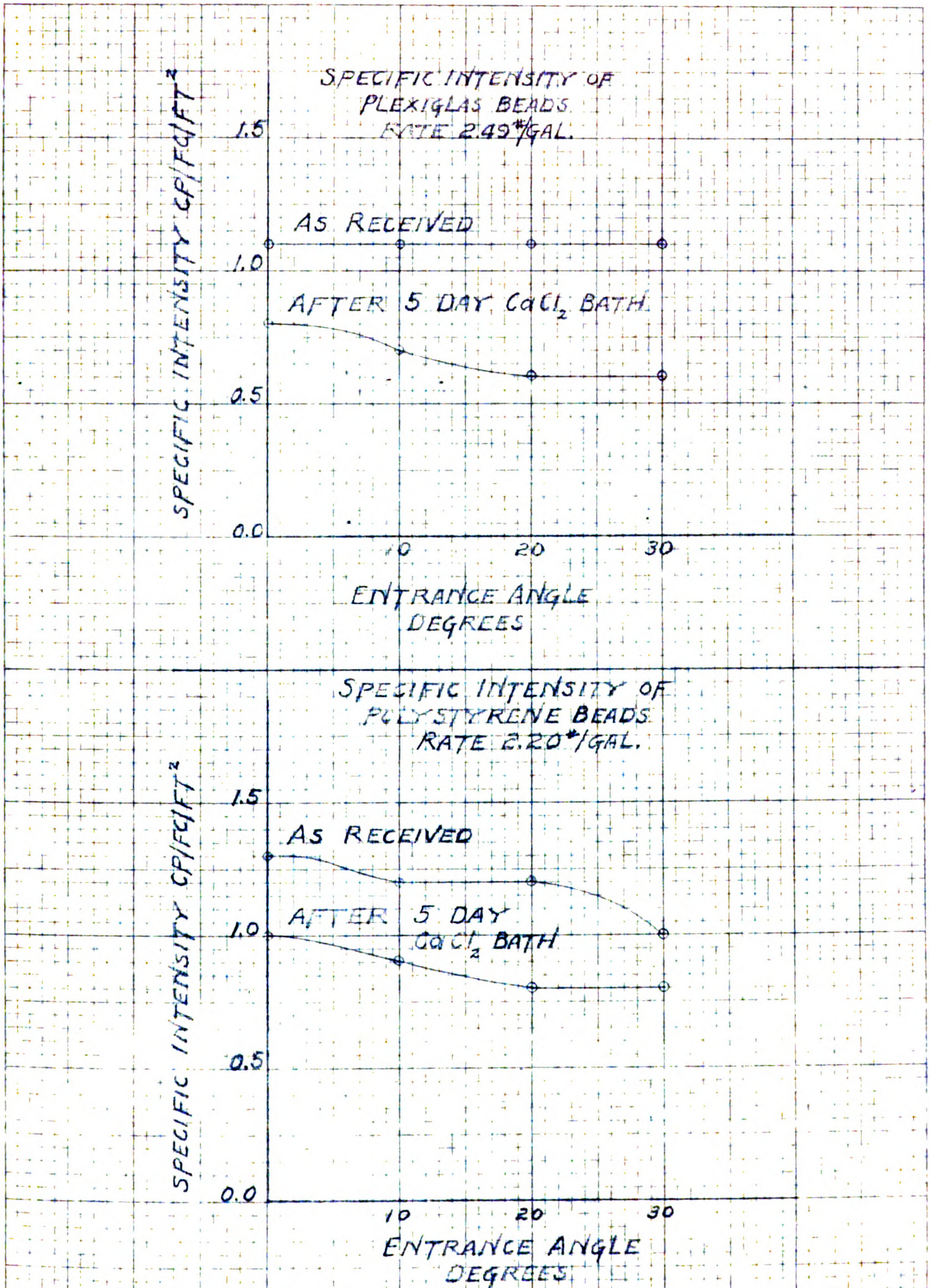

SPECIFIC INTENSITY OF PLEXIGLAS BEADS RATE 2.49#/GAL.
SPECIFIC INTENSITY CP/FC/FT²
1.5
1.0
0.5
0.0
AS RECEIVED
AFTER 5 DAY CaCl₂ BATH
10
20
30
ENTRANCE ANGLE DEGREES
SPECIFIC INTENSITY OF POLYSTYRENE BEADS RATE 2.20#/GAL.
SPECIFIC INTENSITY CP/FC/FT²
1.5
1.0
0.5
0.0
AS RECEIVED
AFTER 5 DAY CaCl₂ BATH
10
20
30
ENTRANCE ANGLE DEGREES

FIG. 15

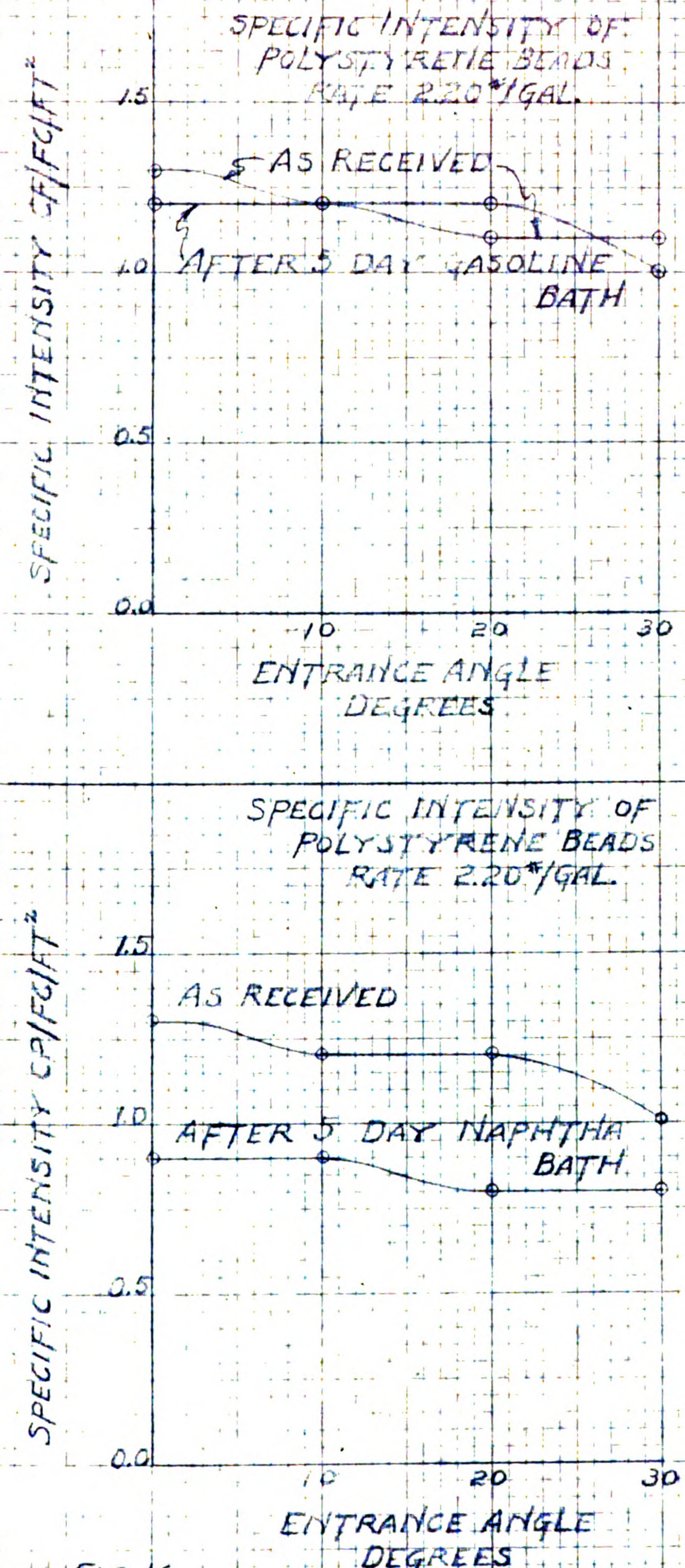

SPECIFIC INTENSITY OF
POLYSTYRENE BEADS
RATE 2.20#/GAL.
SPECIFIC INTENSITY CP/FC/FT²
1.5
1.0
0.5
0.0
AS RECEIVED
AFTER 5 DAY GASOLINE BATH
10
20
30
ENTRANCE ANGLE
DEGREES
SPECIFIC INTENSITY OF
POLYSTYRENE BEADS
RATE 2.20#/GAL.
SPECIFIC INTENSITY CP/FC/FT²
1.5
1.0
0.5
0.0
AS RECEIVED
AFTER 5 DAY NAPHTHA BATH
10
20
30
ENTRANCE ANGLE
DEGREES

FIG. 16

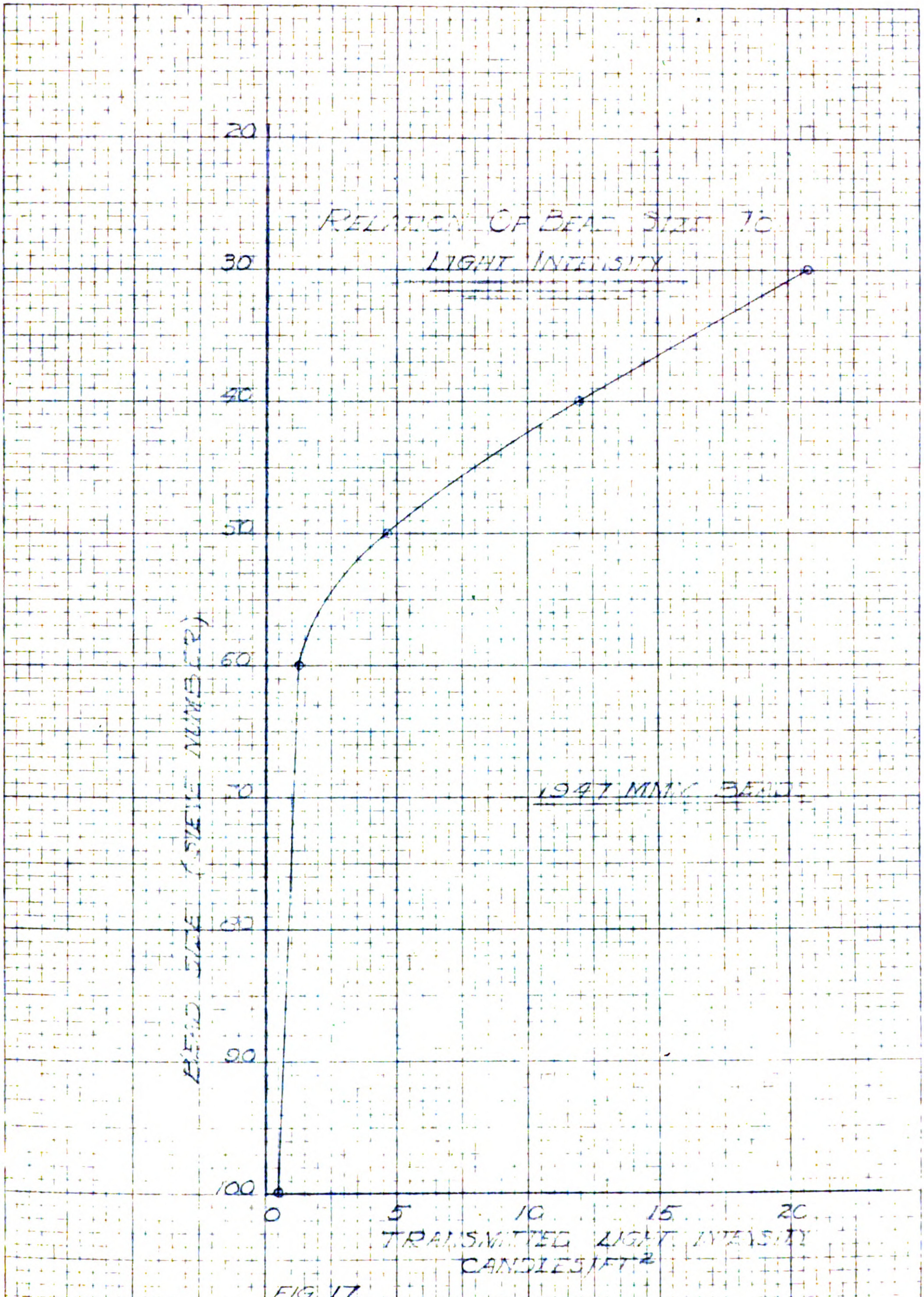

RELATION OF BEAD SIZE TO
LIGHT INTENSITY
BEAD SIZE (SIEVE NUMBER)
20
30
40
50
60
70
80
90
100
0
5
10
15
20
TRANSMITTED LIGHT INTENSITY
CANDLES/FT²

FIG. 17

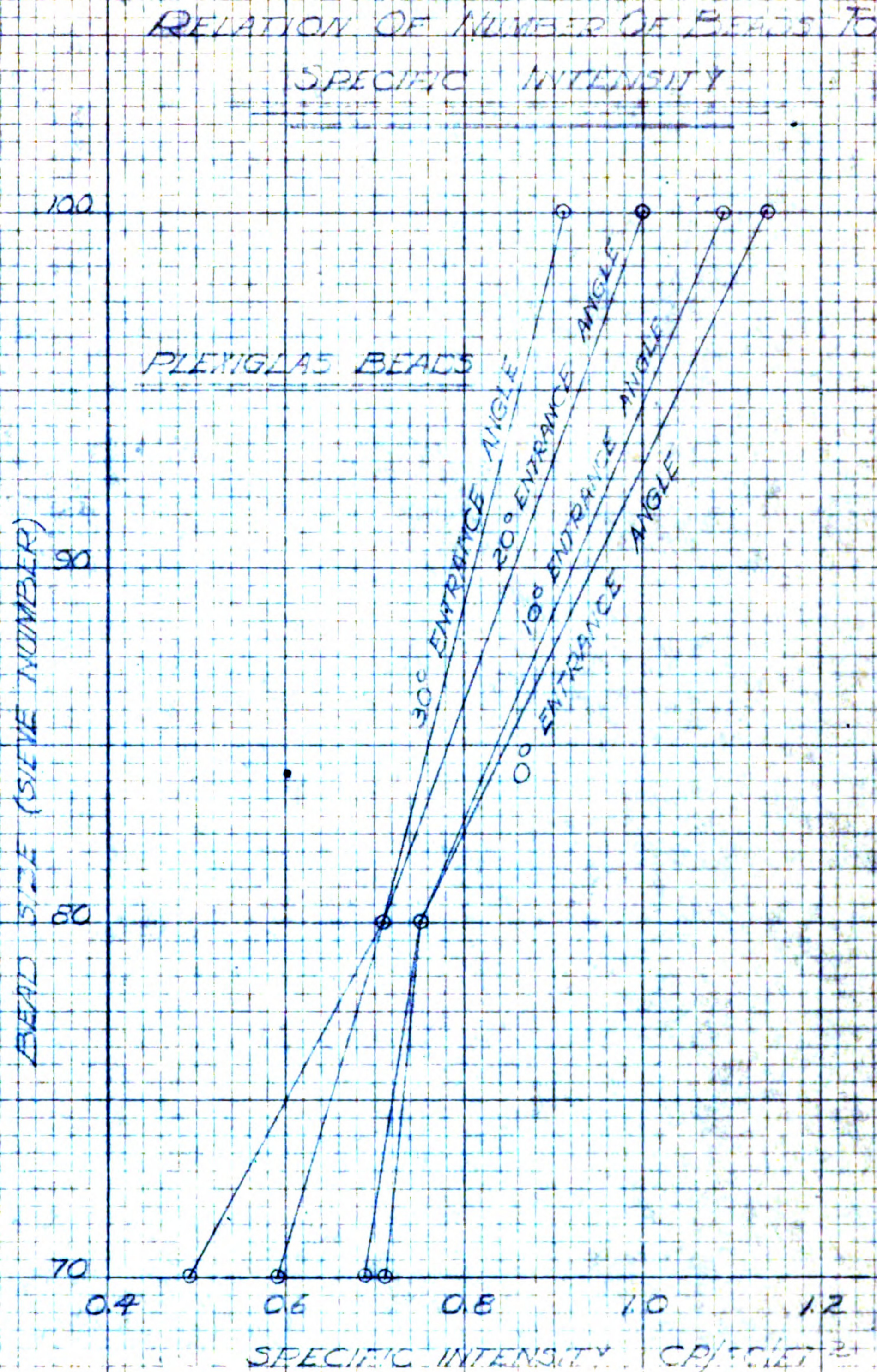

RELATION OF NUMBER OF BEADS TO
SPECIFIC INTENSITY
PLEXIGLAS BEADS
30° ENTRANCE ANGLE
20° ENTRANCE ANGLE
10° ENTRANCE ANGLE
0° ENTRANCE ANGLE
BEAD SIZE (SIEVE NUMBER)
100
90
80
70
0.4
0.6
0.8
1.0
1.2
SPECIFIC INTENSITY CP/FEET²

FIG. 18

CHAPTER IV STRENGTH PROPERTIES

CRUSHING STRENGTH

The average crushing strength of the beaded material was determined by placing one bead between two highly polished steel planed surfaces and loading at the rate of 250 grams per second until failure.

Twenty-five beads were crushed in this manner and the average of these values was taken as the value to be used in determining the average crushing strength.

A diagramatic sketch of the apparatus used in this test is shown in Figure 19.

A single Plexiglas bead (passing 60 sieve and retained on 100 sieve) is placed on a movable anvil "C" directly under the stationery highly polished surface "D". With the bead directly under "D" and resting on "C", small shot is poured from can "A" into can "B" until the bead is crushed. Arm "E" drops down slightly when the bead is crushed. The weight of the shot used to crush the bead is carefully noted and recorded.

This process is repeated twenty-five times, recording the weight of shot used each time.

The average crushing strength in kilograms is determined by taking the average weight of shot used to crush the 25 beads and multiply by the factor 10.9 and divide by 1,000 grams.

The factor 10.9 is obtained by dividing the dimension b(17.875) by the dimension a(1.64). By taking the weight of shot used and multiplying by this factor, $(\frac{17.875}{1.64} = 10.9)$, the actual force that is applied between the two highly polished surfaces "C" and "D" is

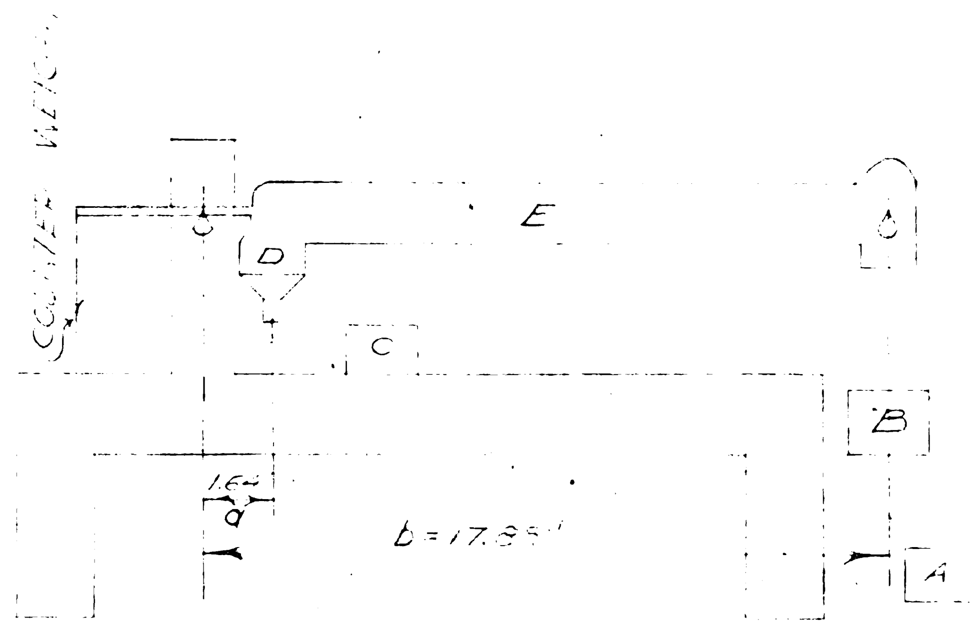


FIG 19 CRUSHING STRENGTH APPARATUS

obtained.

The results of the average crushing strength of Plexiglas beads which have been subjected to (1) room temperature, (2) 144°F temperature, and (3) negative 2°F are shown in Table XX. The author was interested in determining what effect temperature would have on the crushing strength of Plexiglas beads.

The results of Polystyrene Type II beads, crushed at room temperature, are shown in Table XXI.

Table XXII shows the results of Cataphote Type I beads, crushed at room temperature.

The plastic beads were screened to pass a #60 sieve and be retained on a #100 sieve. The glass Cataphote beads were screened to pass a #30 sieve and to be retained on a #40 sieve.

The Michigan State Highway Department Specifications require that Type I bead must have an average crushing strength of 7.5 kilograms and that Type II must have 2.5 kilograms. The reason that the Type II bead crushing strength is lower than Type I is that there are many more beads to withstand the pressure caused by the vehicles and also the paint binder gives the Type II bead the extra needed support.

As shown in Tables XX and XXI, the Type II Polystyrene Plexiglas beads meet the Michigan State Highway Department Specifications for the Type I bead. Obviously, as far as crushing strength is concerned, Plexiglas beads are very practicable for highway marking material.

The author believes that it is just coincidence that both samples subjected to temperature changes showed a higher average crushing strength than those which were subjected to only room temperature.

TABLE XX

Average Crushing Strength Of Plexiglas Beads

Trial	Room Temperature	144°F	-2°F
1	728 grms	707 grms	716 grms
2	658	728	702
3	671	673	703
4	669	649	701
5	668	658	740
6	680	669	759
7	696	651	685
8	670	666	700
9	676	676	729
10	652	693	703
11	665	691	Total 7,138 grms
12	653	707	
13	661	732	Average Crushing Strength =
14	646	684	
15	647	688	$\frac{7,138(10.9)}{10(1,000)} = 7.8$ Kg.
16	647	702	
17	642	692	
18	648	740	
19	651	688	
20	653	701	

(Continued on next page)

TABLE XX (CONT.)

Average Crushing Strength of Plexiglas Beads

Trial	Room Temperature	144°F
21	663	717
22	649	707
23	650	736
24	660	737
25	645	685
26	665	
Total	17,123 grms	17,377 grms

Average Crushing Strength =

$$\frac{17,123(10.9)}{26(1,000)} = 7.2 \text{ Kg.}$$

Average Crushing Strength =

$$\frac{17,377(10.9)}{25(1,000)} = 7.6 \text{ Kg.}$$

TABLE XXI

Average Crushing Strength of Polystyrene Beads

Trials		Trials		Trials	
1	700 grms	10	700 grms	18	689 grms
2	712	11	741	19	731
3	700	12	703	20	708
4	703	13	695	21	696
5	711	14	710	22	718
6	709	15	719	23	726
7	729	16	716	24	727
8	733	17	703	25	693
9	695			Total	17,763

Average Crushing Strength =

$$\frac{17,763(10.9)}{25(1,000)} = 7.8 \text{ Kg.}$$

TABLE XXII

Average Crushing Strength Of Cataphote Beads

Trials		Trials		Trials	
1	502 grms	9	526 grms	17	713 grms
2	750	10	660	18	693
3	542	11	519	19	713
4	627	12	705	20	724
5	695	13	526	21	967
6	616	14	615	22	694
7	682	15	704	23	735
8	706	16	709	24	590
				25	967
				Total	16,800 grms

Average Crushing Strength =

$$\frac{16,800(10.9)}{25(1,000)} = 7.4 \text{ Kg.}$$

TABLE XXII

Average Crushing Strength Of Cataphote Beads

Trials		Trials		Trials	
1	502 grms	9	526 grms	17	713 grms
2	750	10	660	18	693
3	542	11	519	19	713
4	627	12	705	20	724
5	695	13	526	21	967
6	616	14	615	22	694
7	682	15	704	23	735
8	706	16	709	24	590
				25	967
				Total	16,800 grms

Average Crushing Strength =

$$\frac{16,800(10.9)}{25(1,000)} = 7.4 \text{ Kg.}$$

WEAR TEST

The object of this test is to determine the durability of four paint stripes, one containing no beads, another containing glass beads, a third Polystyrene beads and a fourth Plexiglas beads.

A four wheeled rubber-tired dolly was pulled over the four stripes until 100% failure was noted. The total failure was considered to be that point at which the paint over which the wheel traveled was completely worn through. The number of trips required by each wheel to produce this failure was carefully noted and recorded. The average number of trips by the four casters to produce 100% failure was taken as the final result.

The results of the test are charted in Figure 20.

PROCEDURE

Panels

Four stripes, each four inches by eighteen inches, were painted on one long continuous panel of plywood using a doctor blade to insure a uniform thickness of .015 inches.

To one of these stripes the author applied 11.6 grams of Type I glass beads which was at the rate of six pounds of glass beads per gallon of paint. To another stripe was added 4.3 grams of Polystyrene beads which is equivalent to 2.20 pounds of Polystyrene beads per gallon of paint. It should be remembered that there is in 2.20 pounds of Polystyrene beads, approximately the same number as in 6.00 pounds of glass beads.

To the third stripe was added 4.8 grams of Plexiglas beads which is equivalent to 2.49 pounds per gallon of Plexiglas beads or 6 pounds per gallon of glass beads.

The fourth panel was left without the application of any beads to be used as a control for the other stripes.

The paint was allowed to dry for five days at room temperature and humidity before the actual wear testing was started.

Dolly

The dolly used by the author consisted of four rubber-tired casters, one-half inch wide by one and three-quarters inches in diameter, fastened to a small wooden platform twelve by seven by three-quarters inches.

The four rubber-tired castors were staggered in such a way that no two of them would travel in the same path. In this way the author was able to perform four tests at one time.

On top of the small wooden platform was placed a seventeen pound weight which made the total dolly weigh approximately eighteen pounds. This meant that theorectically each wheel of the dolly was carrying four and one-half pounds.

The four wheels of the dolly were placed at an angle of twenty degrees with the direction of travel in order to create a slight skidding effect as well as a rolling effect.

Testing

A very thin layer of sand was applied to each panel before the start of the test. This sand was used to act as an abrasive and thereby greatly reduce the time required to complete the test. After each fifty trips across the stripes the sand was redistributed and the test continued.

Ropes were fastened on both the front and back end of the platform. The dolly was propelled by pulling these ropes, first in one direction and then in the other. Guides for the dolly were placed along the two edges of the panel to insure proper alignment.

It was pulled at an angle of thirty degrees with the four stripes which means that each castor actually travelled a distance of 4.62 inches along each of the stripes.

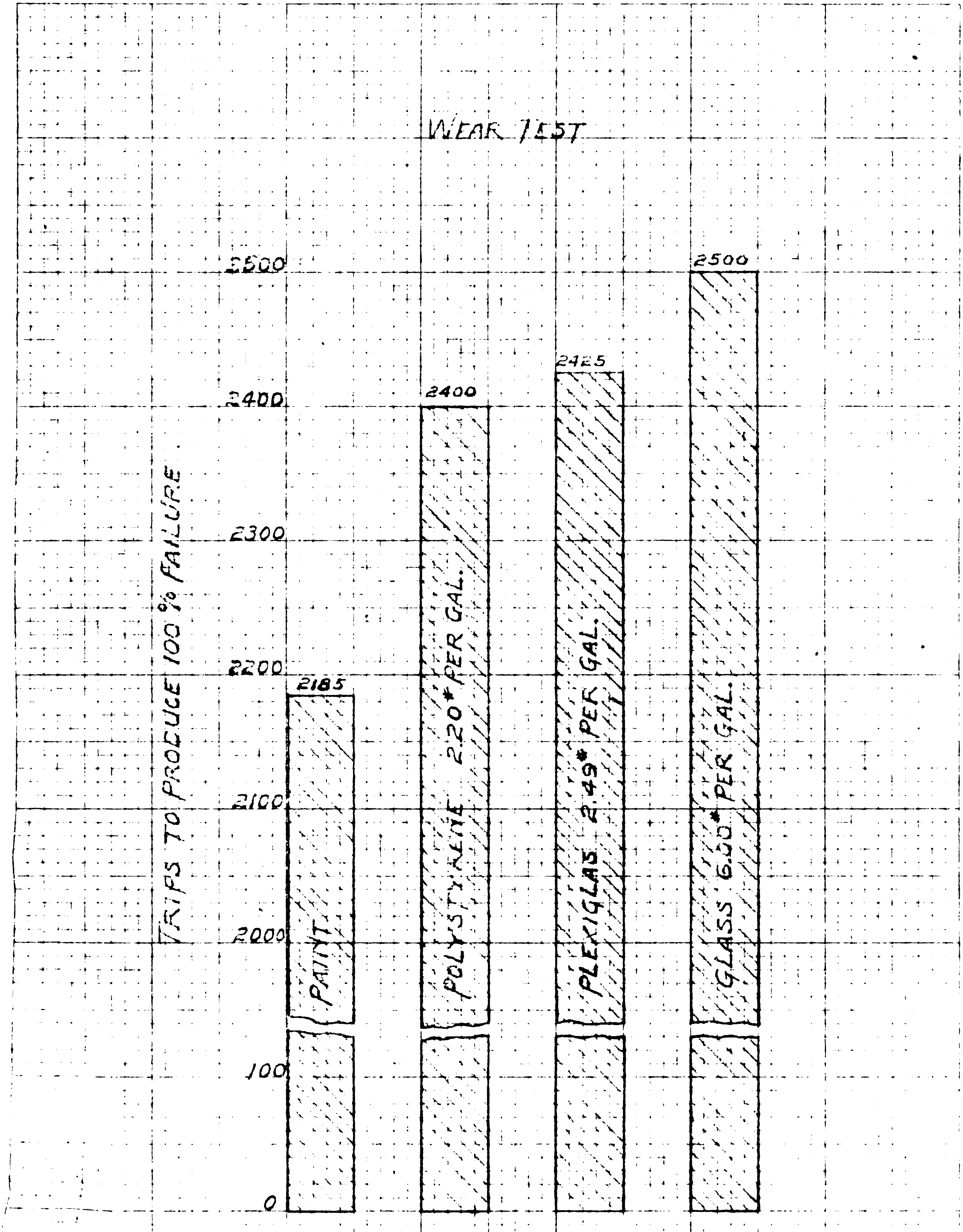

WEAR TEST
TRIPS TO PRODUCE 100% FAILURE
2500
2400
2300
2200
2100
2000
100
0
2185
2400
2425
2500
PAINT
POLYSTYRENE 2.20* PER GAL.
PLEXIGLAS 2.49* PER GAL.
GLASS 6.00* PER GAL.

FIG. 20

HARDNESS AND ABRASION

The hardness of glass beads lies between the range of 4.5 and 6.5 on the Mohs scale of hardness. The hardness of both Polystyrene and Flexiglas beads is approximately 3 or 4 on the Mohs scale. Polystyrene is slightly harder than Flexiglas.[1]

For convenience, Mohs scale of hardness is shown below:

1.	Talc	6.	Feldspar
2.	Gypsum	7.	Quartz
3.	Calcite	8.	Topaz
4.	Fluorite	9.	Corundum
5.	Apatite	10.	Diamond

Although the surface hardness of Flexiglas is not as great as glass, Flexiglas is a resilient material and was found to withstand abrasion nearly as well as did glass. The ability of the Polystyrene beads, on the other hand, to resist abrasion is very poor.

[1] Handbook of Chemistry and Physics, 31 edition
Chemical Rubber Publishing Company

CHAPTER V CONCLUSIONS

SUMMARY

As has previously been stated, the use of plastic (Methyl Methacrylate and Polystyrene) beads for pavement center-line and lane marking materials can not be economically justified at today's prices, since the plastic beads cost approximately three times as much as do glass beads.

The crushing strength of Polystyrene beads is fairly high, 7.8 Kg. The crushing strength of Plexiglas was found to be 7.2 Kg.

Polystyrene beads, which tested slightly higher than Plexiglas beads in nearly all the tests run by the author, were found to be very susceptible to abrasion. The ability to withstand abrasion of the white paint stripes containing Plexiglas, Polystyrene, and glass beads, placed in order of decreasing efficiency, is glass, Plexiglas, and Polystyrene beads. The surface of the Polystyrene beads was found to be badly marred by abrasion. Faced with this fact, it is doubtful that Polystyrene beads could ever be used for this purpose.

The Polystyrene beads were found to have a much better gradation for center-line marking material than did the Plexiglas beads; the Plexiglas beads being too uniform in size.

The color of the plastic beads, while transparent, was not as transparent as the glass beads. The plastic beads showed a marked decrease over the glass beads in the number of imperfect beads (excess air, out-of-rounds, surface mars, pits and so forth).

As was stated before, the specific intensity of glass beads is 1.4, of Polystyrene beads is 1.3, and of Plexiglas beads is 1.1. The specific intensity of the plain 1951 Michigan State Highway white paint was found to be 0.6 CP/FC/SQ.FT.

Naphtha was found to lower slightly, the specific intensity of both the plastic beads tested. It was further found that gasoline had practically no effect on the reflectivity of Polystyrene and very little effect on Plexiglas beads. A saturated solution of calcium chloride was found to have a slight reducing effect on the reflectivity of both plastic beads.

Confronted with the data collected by the author, he recommends that the use of glass beads be continued until a better and more suitable material is found.

In order to decrease the number of night time accidents, which take the lives of hundreds each year, a constant effort to improve the present glass bead or find a more effective material must never end.

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