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HIGHWAY SIGNING RESEARCH

A SURVEY OF MATERIALS AND RESEARCH NEEDS RELATING TO THEIR USE

THD No. 5-1-65-86
SwRI Project 07-1650
FINAL REPORT ON PHASE I

by

C. G. Harman

for

Texas Highway Department
State Highway Building
Austin 4, Texas

and

Bureau of Public Roads
Washington, D. C.

July 21, 1965

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SUMMARY AND CONCLUSIONS

I. INTRODUCTION

A program on Highway Signing Research, sponsored jointly by the Texas Highway Department and the Federal Bureau of Public Roads, was inaugurated at Southwest Research Institute on December 21, 1964. The overall objective of the study was to identify and evaluate the qualities for optimum sign effectiveness and serviceability, to delineate objective criteria for specifying these qualities, and to establish test procedures and requirements to evaluate signing materials with respect to these criteria. The emphasis was to be on retroreflective signing materials, and their characteristics at night and under adverse environmental conditions, although other materials and conditions were also to be considered as part of the investigation.

This project, designated as Phase I of a more comprehensive study, had as its specific objectives a critical evaluation of current knowledge and practices, the identification of specific problems needing additional research, and the delineation of plans for accomplishing a selected group of selected tasks.

The objectives of this work were achieved through a study of literature and patents, contacts with manufacturers of signs and sign materials and visits to sign shops. Observations were made of signs, sign environment and general field conditions. Useful information was supplied by 46 state highway departments concerning their practices and specifications. In addition, attendance at technical meetings, at displays of commercial instruments, and by visits to manufacturers, served as useful sources concerning photometric and other instrumentation.

The study to date has indicated the need to evaluate the serviceability of signing materials, to examine the adequacy of current performance specifications and to develop standardized objective test procedures and photometric instrumentation.

These conclusions have been borne out, in fact emphasized, by information gained by contacting state highway departments, by conferences and correspondence with manufacturers of sign facing materials and signs and by first-hand visitations to selected, widely differing field installations.

II. SUMMARY

The construction and design of signs and sign supports appears to have been extensively studied from the standpoints of engineering research and service. This has been well covered in the literature, in literature reviews and in engineering and purchase specifications.

The review of available literature indicates that extensive studies have been made regarding visibility and legibility of highway signs, and that the present recommendations and specifications of Bureau of Public Roads and American Association of State Highway Officials are quite generally accepted as satisfactory in regard to letter size, type, spacing, and color combinations, providing these recommendations are properly applied for the design speed and characteristics of the highway. Additional studies are perhaps needed and to some extent underway in the determination of attention-gaining characteristics, in establishing the optimum reflective characteristics and contrast of background materials, and means of preventing the "blanking" out of signs by fog and dew.

Reflectorized sheeting and its equivalents were discussed in the patent literature, and details of constitution were extensively described. These facings are surfaced with a layer of glass beads so as to produce retroreflectiveness. The literature on flat-faced retroreflective sheeting is mostly in the form of patents. The numerous patents on the subject contain detailed information on the structure and construction of pre-prepared beaded sign facings. Technological problems in the art of making the facing, insofar as considerations of highway signing are involved, are mostly those of trading off available optical characteristics, chemical and physical compatibility, weather stability, and economic aspects (of availability and manufacture) between the various components and materials in order to arrive at an optimum compromise product.

Several types of sign facings were discussed in the literature. These are: (a) porcelain enamel on steel, (b) porcelain enamel on aluminum, (c) retroflective sheeting, (d) prefabricated sign blanks with reflective facings, (e) prefabricated sign blanks with nonretroreflective facings, (f) fluorescent sheeting, (g) reflective lenses and buttons made of organic resin and of glass, (h) beads-on-paint, (i) nonreflective paint and (j) externally illuminated and internally illuminated plastic signs.

Background information on porcelain enamels in the literature is extensive. Not very much is said, however, about porcelain enameled highway signs. Standards, tests, methods of evaluating and rating, properties and behavior patterns are well covered. The Porcelain Enamel Institute has issued documents on these factors and further work is in progress. Some standards also have been issued by ASTM.

An extensive study, covering a period of more than 15 years was conducted by the National Bureau of Standards for the Porcelain Enamel Institute. This study included outdoor weathering panels, service behavior, and laboratory tests. The degree of degradation was measured in terms of gloss and of color stability. With but few exceptions, there was a direct correlation between acid resistance and weather resistance. The acid resistance tests were very rapid. The ease of cleaning also was directly correlated with durability.

Literature dealing with the durability of sign composites and sign components was found to be limited and very specific in nature. Most of the information seems to be widely scattered and discussed under separate materials headings. Corrosion, chemical stability and weathering are discussed in detail, but not usually directly applicable to signing.

The durability of exterior paints also was widely discussed, and much of this has a bearing on beaded signs. A general conclusion concerning paint durability seems to be that the chief aggressives are moisture, ultraviolet radiation, and lack of stability or bonding to the substrate.

Little information was available in the literature regarding the evaluation of signing materials with respect to serviceability, maintenance, useful life expectancy, fabricating characteristics, degradation mechanisms, types of commercial facings materials, standards, reasons for retiring signs from service, short time accelerated tests, and the like. Undoubtedly much data in this respect exist in the files of the different state highway departments and of the manufacturers of signing materials, but few recognized standards are available and generally accepted.

It is clear that one of the most promising approaches to the problem of rating of sign materials is on the basis of potential service life. Tentatively, at least, it appears that different test methods would be used for different types of materials.

Information on the durability of sign materials has a direct bearing on sign maintenance and on the development of improved maintenance procedures. Engineering and procedural aspects of sign maintenance were discussed in detail in the literature and in some directives and memoranda.

The report contains a limited discussion of new types of materials for fluorescent and phosphorescent surfacing and signs. Since these materials are not now contemplated for use in signs, the subject was not extensively reviewed.

The literature on instrumentation is voluminous. The review which has been made indicates that a significant amount of the published work deals with involved laboratory types of instruments which have been designed for special purposes. Attempts have been made to study sign effectiveness by instrumental procedures and photographic procedures.

Color theory and measurement is represented by considerable literature, some of it dealing with attempts to simplify the concepts and measurements. Some of it concerns efforts to make it a more exact science but seems to the uninitiated to be compounding the complexity. In general, the theoretical aspects of color seem to be in competent hands, but with a considerable lag in practical applications in most fields.

All of the states, except Alaska, have specifications for reflective sign facing materials, but many of them have little or no laboratory facilities. In some cases the specifications seem to be based on original work by the Highway Departments. There does not seem to be a general agreement concerning what is actually required of facing materials.

All of the manufacturers of sign facing materials have specifications or standards concerning their products. No two of these are identical, although they may be similar. Descriptions and standards appear to be based more on products than objective properties.

III. CONCLUSIONS AND RECOMMENDATIONS

As new signing concepts and new materials are produced, there is a definite need to develop objective specifications and performance test procedures that are both repeatable and reproducible. Standardization of specifications and test requirements are necessary to insure competitive purchase of materials and completely satisfactory performance both in regard to visual effectiveness and durability.

Quantitative measurements of various photometric parameters are essential for performance tests of materials, for monitoring of deterioration in service, and for objective correlation of studies of driver perception of visibility and legibility. Instrumentation for these purposes needs to be developed and standardized to insure adequate performance of signing materials and to provide repeatable and reproducible test procedures for competitive purchase of materials.

As a result of this survey of background information, a program of further work is recommended. The specific objective would be to obtain, through field studies and related laboratory work, sufficient information on which to judge the adequacy of current performance specifications for sign facing materials. The ultimate longer-range objective would be to develop laboratory acceptance tests for use in specifications and standards for materials.

The general technical areas recommended for additional investigation are:

(1) Durability, including failure mechanisms
(2) Causes for sign replacement
(3) Cleanability
(4) Ease of fabrication
(5) Photometric properties
(6) Selection and development of photometric instruments
(7) Determination of potential life of signs, enumeration of required use life and development of methods for determining the cost per year of signs.

Problems of sign effectiveness and signing, per se, are not within the scope of the recommended investigations. The reason for this limitation is simply because other work in progress and contemplated in this general field appears to be adequate.

A part of the objective of the recommended further investigation would be to establish methods for the rating of signs. Realistic standards should be established concerning pertinent items in the enumerated tabulation listed above. In some cases, suitable methods may exist for such rating; however, for others there is not enough known to establish suitable standards. It is recommended that research be conducted in order to remove these inadequacies. In addition, it seems desirable to develop photometric instrumentation which could serve as a basis for judging sign conditions in the field.

The objectives discussed immediately above are primarily directed toward facing materials, but the performance of facing materials cannot be completely divorced from either the backing material or the sign structure. Consequently, appropriate new information on the materials problems in these related fields is required.

In summary, it is recommended that work be undertaken and directed toward the long-range objective of developing short-time laboratory acceptance tests. Sufficient information should be obtained to permit the up-grading and revision of standards, which should include objective service requirements based on basic physical, chemical, and mechanical properties.

The problems outlined above are interrelated and should be studied concurrently.

There are some areas that are not directly interrelated on the same basis as the tasks discussed above. Some of these are as follows:

(1) Studies directed toward standardization of sizes of similarly shaped signs.

(2) Standardization of sign accessories such as nuts, bolts, etc., as a means for value analyses.

(3) Corrosion protection of steel sign blanks, including advanced standards and control methods for the process used, such as coating and plating.

(4) Detailed study of the mechanism of deterioration of sign facings to enable rapid estimation of life expectancy.

(5) Detailed study of sign materials specifications of various states and recommendations for consideration of uniform code.

(6) Study of the problem of sign damage due to vandalism and recommendations for approaches to minimize damage due to that cause.

(7) A study of fluorescent, phosphorescent and special materials as a possible new generation for sign facings.

(8) Electrostatic process for making signs.

(9) Method for economical repair of damaged signs in the field.

(10) The importance of reflectorized background.

(11) Determination of detailed cost distributions for signs.

(12) New considerations of the problems of sign black-out due to fog, dew, frost and rain.

PART ONE

PUBLISHED INFORMATION

I. CONSTRUCTION OF SIGNS

A. Sign Supports

Design. The design of sign structures has been standardized by committees of the American Association of State Highway Officials and other agencies(1). It is expected that economical standard designs will be developed to support overhead signs and that these structures will be readily available from various manufacturers(2). The "Texas Highway Department Interstate Signing Standards Index"(3) provided extensive detail with regard to the interstate sign support designs used in Texas, while the "Texas Manual on Uniform Traffic Control Devices for Streets and Highways"(4) furnished the design guide for Texas state highway sign supports.

Materials. The materials normally used in the support structure of the large overhead signs of the interstate system are aluminum and steel. Materials specifications for these were established by ASTM. Concrete is normally used as a foundation material for the sign supports. State highway sign support materials vary with the geographic and climatic conditions. For instance, in Wisconsin(5) the use of treated woods for supports is very popular. Texas uses galvanized pipe and structural steel sign supports on the state highway systems. Delineator and milepost marker posts used in Texas are made from steel wing channel posts. In recent months the experimental replacement of the large section I-beam used to support the interstate exit signs with a modified support containing a "breakaway" feature has been in progress in several locations in Texas. It was found that the rigidity of the original support lead to extensive property damage and additional injury under collision conditions(6).

Specifications. Pertinent specifications of Texas Highway Department are referenced in Appendix I. Other specifications relating to signing materials are listed in Appendix II.

B. Signs

Design. The area concerning the physical design of signs has been extensively covered, and standards have been adopted by the National Joint Committee on Uniform Traffic Control Devices(7) based on extensive research work. Individual states have adopted their own sign standards(3, 4) based primarily on specifications established by the Joint Committee.

Special conditions have warranted the application of unique sign designs such as the louvered sign panels designed by Cysewski to eliminate extensive damage caused by high velocity winds[8].

Materials. No fixed recommendations were offered as to sign materials. Plastic-coated plywood, redwood, tongue-and-groove, aluminum, steel, and other materials are being successfully used[2]. This is dependent largely on local experience and local availability of satisfactory materials. Most states have established their own specifications. The sign facing materials and durability of the signs are discussed in subsequent sections of this report.

Specifications. Most states have specifications concerning the materials used for highway signing in that individual state. For the state of Texas a listing is given in Appendix I. (A partial list of specifications used in other states is given in Appendix II.)

II. TYPES OF SIGN FACINGS

A. Reflectorized Facings: General

In this category is included reflex light-reflecting signs and markers. Such reflection is to be distinguished from that produced by a plane reflector, such as a mirror or a polished surface. With the plane reflector, an incident ray is reflected as a ray at an angle equal to the angle of incidence. Still another type of reflection, not included as "reflectorized," is that produced by diffusing surfaces such as blotting paper where the incident ray is reflected with approximately equal intensity over a wide angle. In the case of the plane reflector, an observer must be located substantially on the line of reflection in order to see the reflected light where it will be of high intensity. In the case of the diffuse reflector, the diffused light is reflected over a wide angle but is always of low intensity. The reflectorized sign of interest in this section is based on a reflex light-reflecting or "reflexive" principle. With this system, the driver of an automobile whose headlights illuminate the reflectorized target, even though at an angle, will be able to see intense reflected light at a great distance.

Lenses properly shaped and mounted return a high-intensity beam at small angles when illuminated by lights from a vehicle. Fairly large glass or plastic lenses so used can serve as delineators for symbols, letters, markers and signs. Retroreflective surfaces or paint employs the same principle. Very small regularly shaped elements of transparent material, such as glass, in the shape of spheres, cubes, and other configurations may be employed. It is particularly effective for the small "lenses" to have heights approximately equivalent to their "diameters." Small opaque reflecting objects such as metal flakes also have applications in reflective surfacings.

When very small transparent "lens" elements are placed close together over a large surface, a bright reflex reflection is obtained. It is desirable that the elements be backed by a highly reflective surface, and that they be attached or bonded to the surface with appropriate layers or coatings of a transparent adhesive.

The use of beads in sign reflectorization was reviewed by C. B. Hastings and C. M. Foster(15) in a report for the Texas Highway Department. This report contains a brief history of beaded signs, theory of bead reflectorization, optical properties of beads, influence of light absorption and colored binders and the preparation of beaded signs.

The general purpose is fairly clear from the descriptive matter in the preceding sections. The primary functions of reflectorized signs are for attracting attention and for creating maximum night visibility without the necessity of providing illuminated signs.

Road signs and markers of the reflex type have greater visibility at night than do ordinary signs and markers. To the occupants of an approaching automobile, less of the reflected light is dissipated outside of the field of viewing than is so with other types. The reflected light, being concentrated in a narrow cone, automatically returns toward the headlights and occupants of the vehicle.

Jainski(9) made suggestions for the evaulation of light reflector materials for signs, and included also conclusions regarding correlation with practical effectiveness and durability. Some materials for signs were described by Angelini(10). German materials, including reflecting paints, were described in general terms by Heller(11). Some materials used on the New Jersey Turnpike for signing were discussed by J. R. Crosby(12) from the standpoint of durability, appearance, structural adequacy and maintenance. Signs and materials used for George Washington Bridge approaches were discussed by Watson(13).

The principles of reflectorized beaded paint and plastic sheet were described, mainly in theoretical terms, by James and Hayward(14).

An analytical treatment of the relation between bead size, bead embedment and binder film thickness is useful in connection with an understanding of the general principle of beaded reflectorized signs. This has been well presented by Hastings[15, 16] (see Fig. 1).

B. Retroreflective Materials

1. Reflective Sheeting

Schramm[17], in 1906, coated fabric with a mixture of minute glass globules in a plastic adhesive vehicle. Colored material was made by first applying a thin layer of pigmented adhesive. A screen for luminous signs was prepared by embedding solid particles in transparent adhesive material, according to a patent issued in 1916[18]. In 1924 a retroreflective highway sign[19] was prepared using a reflecting surface to which was applied a light-diffusing material.

Translucent sheet material was described by Sherer[20, 21] in which a translucent backing was coated with solids suspended in an adhesive vehicle. A sign was described in 1933 by Gill[22] that was composed of tiny reflecting elements embedded to about half their diameter in an adhesive reflective backing. A similar self-illuminating sign was made by Reiss-Schmidt[23], using a mirror-like reflecting backing upon which was applied a transparent adhesive filled with tiny reflectors. When desired, the transparent adhesive was colored with a dye soluble in it.

A patent issued to Fredrick Hunter in 1939[24] described a method for manufacturing signs which employed several layers applied to a rigid backing. The base layer was a solidifiable opaque reflecting material in which was mounted a continuous layer of light-transmitting beads. A smooth cover-coat of transparent cementitious plastic was applied to the face of the sign. A reflectorized retroreflective sheet comprising a composite of transparent plastic filled with a layer of transparent beads was developed by Grote[25].

Spherical lenses mounted in transparent material and backed by a sheet of reflecting foil was developed primarily as a reflecting element[26]. Rodli[27] devised a combined highway surface and marker using a pigmented paint-like binder of the oleoresinous type filled with transparent autocollimating units (glass beads). Another reflecting beaded paint was patented by Shuger[28]. This employed a reflecting binder and at least 50% of autocollimating units preferably glass beads.

Eckel[29] described a colinear reflector containing concentric spherical media in which the radius of the outer sphere was twice that of the inner sphere. The ratio of the index of refraction of the inner sphere to that of the outer sphere was in the range of 1.62 to 1.50.

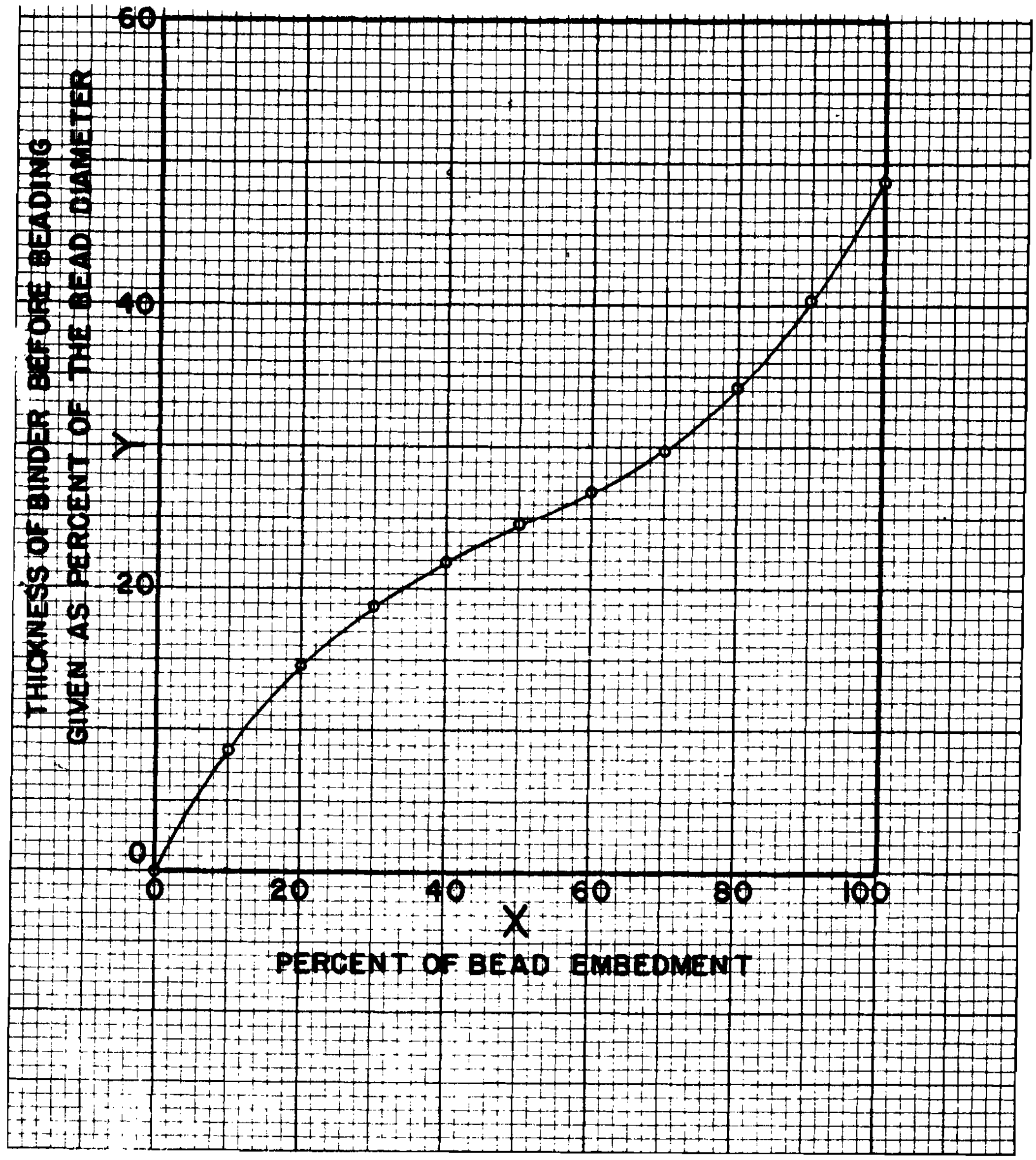


FIGURE 1. RELATIONSHIP BETWEEN AMOUNT OF BINDER APPLIED AND BEAD EMBEDMENT (For 85% Perfect Packing)

The development of adhesives and plastics began to take a prominent place in reflectorized signs about 1940. Drew developed good adhesive sheeting in 1939[30] in which the back surface of the tape was inactive to the adhesive coating on the other side. Most of the earlier work was directed toward the development of adhesives, and attention also was given to the development of bonds for sheet abrasives.

The compositional and chemical details of retroreflective sheeting is extremely complex. These factors have undergone great chages in the interest of improved products. Changes are still in progress, and to a considerable extent polymers, adhesives and plastics used for retroreflective sheeting as little as five years ago may not equal the performance of current materials. Consequently, a review of the history of resins, plastics and other compositional factors of retroreflective sheeting does not contribute much of value to the highway signing project. The physics and geometry of sign facing materials is germane, to the extent that it will help in understanding the behavior, use, and evaluation of signs. The chemistry, or at least the chemical properties of the constituents in end-product materials that are being employed in sign facings, is of interest since it has a bearing on methods for evaluation and possibly on its application. Consequently, compositional factors dealing mainly with developmental and manufacturing problems of sheeting will not be reviewed here.

During the preceding 25 years, new sign materials have been developed to meet the demands of increasing volume and complexity of traffic. A brief review of some of the patents granted during the period from 1941 to 1952 is useful and instructive.

A finish characterized by a high degree of brilliance was described by Farrell[31]. This sheet was so prepared that it gave a three-dimensional appearance. This was made by using a solution of a nonvolatile vehicle in a volatile solvent which, upon drying, formed a transparent film. The system contained a dispersed pigment smaller than 0.5 micron in diameter and mostly of a size equivalent to 1/2 the average wavelength of visible light. In addition, there were dispersed small metal flakes amounting to less than 5% of the aggregate of pigment and metal.

One of the earlier reflectorized signs was patented by White[32]. He used a light-diffusing backing onto which was bonded nonspherical transparent bodies, in an attempt to obtain better retroreflectance properties than hitherto had been accomplished with glass spheres. An improved reflex reflector employing glass beads was described by Palmquist[33]. He found the optimum spacing for spheres of index of refraction of 1.50 to 1.55 to be 1/3 the bead diameter, when the bonding medium had the same index as the glass. The optimum spacing decreased as the index of refraction increased.

It is advantageous to use a minimum spacing to minimize light absorption and the amount of plastic required.

In considering what determines the optimum spacing for a particular glass sphere, elementary lens formulas are not applicable, due mainly to spherical aberration. Smaller beads should be more closely spaced to the reflector than larger ones. Graded bead sizes, providing an optimum size range, are achieved when the smaller beads are 1/2 the diameter of the larger beads.

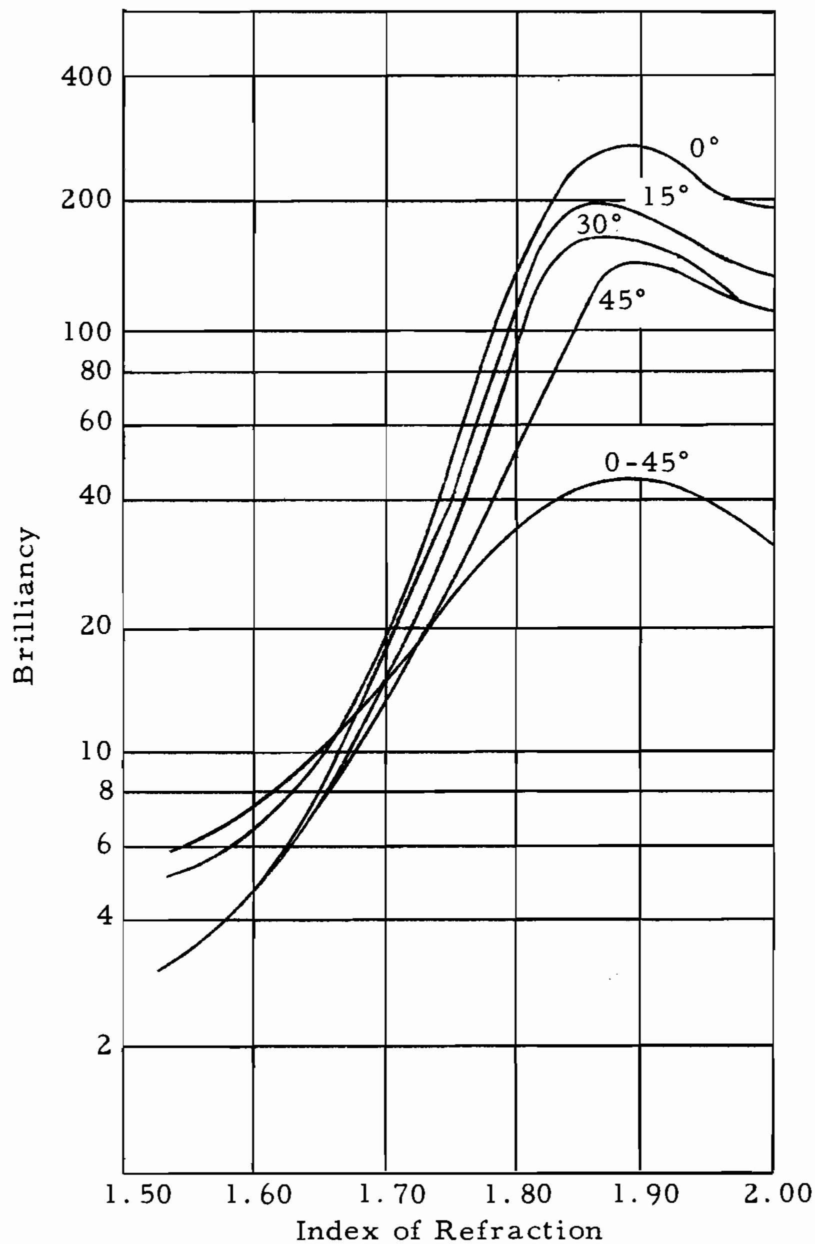
A retroreflective sheeting claimed to be of higher brilliance than was formerly available was described by Gebhard, Heltzer, Clark and Davis(34). Improved brilliancy reflex-reflection characteristics were obtained by employing glass spheres of high index of refraction. Optimum brilliancy was claimed for glass beads having index of refraction in the range from 1.70 to 1.90. The problem is more complex, however, than a simple relation of brilliancy to index of refraction.

Various types of reflective binders were used. When a binder was pigmented with aluminum flakes, a semispecular type of reflection resulted as shown by the curves marked 0°, 15°, 30°, and 45° in Figure 2. A binder pigmented with titanium oxide produced a nonspecular reflection as shown in Figure 2 by the curve labeled 0 - 45°. By using a backing of aluminum foil, reflex-reflection characteristics such as shown in Figure 3 were obtained. The brilliancy also varied with the spacing of the beads from the backing and from each other.

A flexible weatherproof beaded light reflector adapted for outdoor signs was prepared with an integral back coating of water-resistant adhesive which would firmly bond the sheet to selected base surfaces(35). The beads were bonded by a weatherproof pigmented bonding coat, but the beads were exposed for something less than half their volume. The beads themselves rested on a pigmented sizing film. A different optical effect was obtained by separating the row of beads from the reflector sizing coat by a transparent spacing coat.

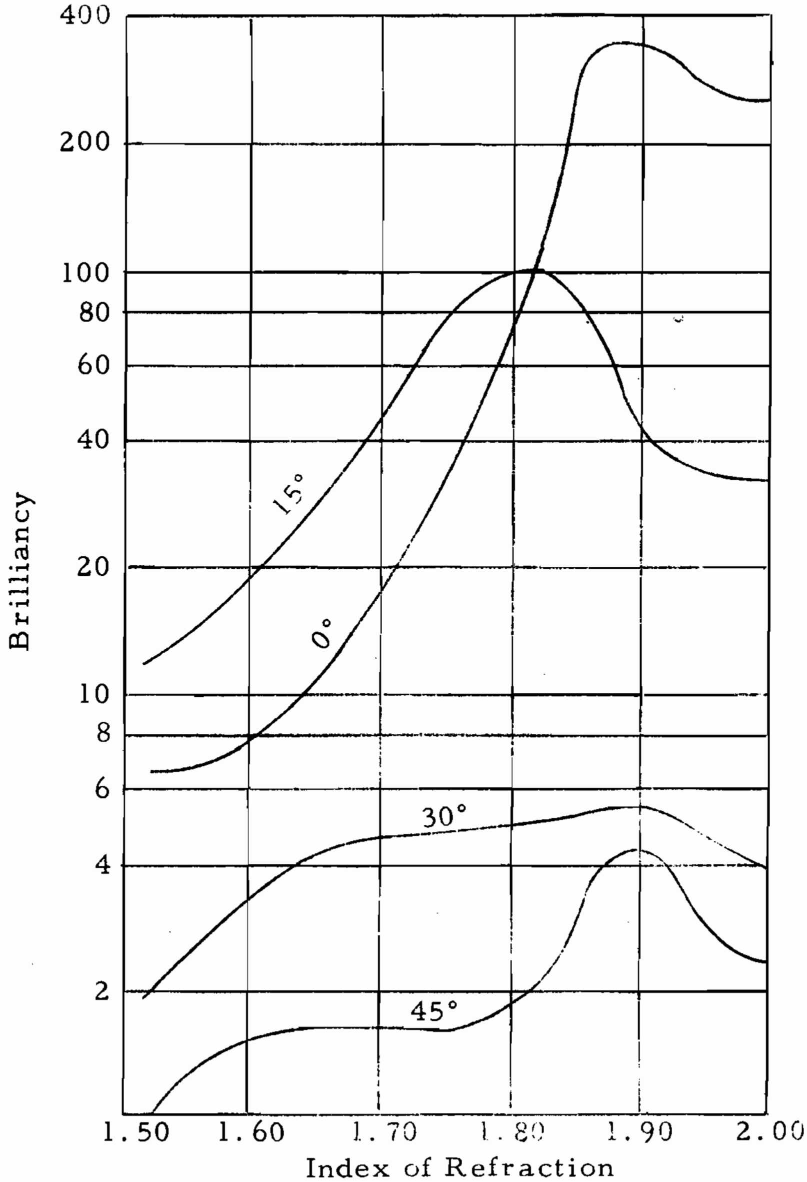
Palmquist(36) described a transparent, retroreflective sheet material, with an adhesive back, that was used to place over existing signs to convert them into reflectorized signs.

A "backless" reflex-reflector sheet that can be readily dry-stripped from the coated paper carrier web and later reused was described in 1944(37). Means for improving and controlling the optical characteristics of retroreflective sheeting were developed on the basis of internal structure(38).



Note: Degrees indicate angles of incidence.

FIGURE 2. BRILLIANCY VS INDEX OF REFRACTION OF BEADS IN A SYSTEM EMPLOYING A BINDER PIGMENTED WITH ALUMINUM FLAKES



Note: Degrees indicate angles of incidence.

FIGURE 3. BRILLIANCY VS INDEX OF REFRACTION OF BEADS IN A SYSTEM HAVING A BACKING OF ALUMINUM FOIL

Where the transparent spacing layer had the same refractive index as the spheres, the optimum spacing distance decreased from about 35% of the sphere diameter at an index of 1.50 to 1.55, to zero with beads of index of 1.85 to 1.90. The optimum spacing was less or greater if the transparent spacing layer which contacted the rear surface of the spheres had an index less or greater, respectively, than the spheres.

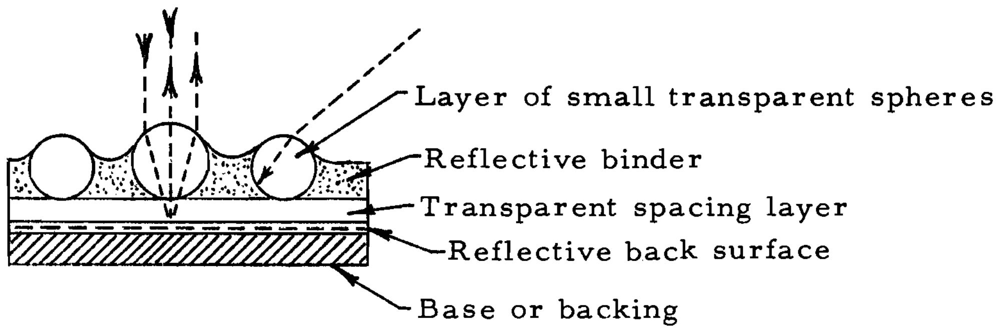
Practical bead diameters lie in the range from about 50 mils to about 3 mils. The use of very small beads is advantageous in reducing costs, improving structural strength, and securing a flat and "smooth" outer surface which lends itself to printing and screen process stenciling. This, in making a sign, a sheet of the reflex-reflector may be painted or printed so as to "black out" certain areas or cover them with a colored coating different from that of the bead binder. Examples of the structure in cross section are illustrated in Figure 4.

Another sign, described by Meigs[39], used a target plate provided with a rib outlining the letters and symbols with projected bosses between. The sign was made with a bead-mounting layer in which beads were bonded to the base furnishing a reflector surface.

Beaded reflective sheeting can be made so the appearance in diffuse daylight is different than the reflex reflecting night appearance[40]. This was accomplished by using external and internal reflective means of different reflective properties as is indicated in Figure 5.

Colored beaded reflex-reflective sheeting for signs can be prepared as shown in Figure 6 as described by Palmquist[41]. A flexible beaded reflex-reflecting sheeting of the transfer decalcomania type is shown in Figure 7[42]. The development of "over-coated" or "flat-top" beaded sheeting is illustrated in Figure 8. A continuous transparent layer of plastic overlays was integrally united to the layer of small transparent spheres[43]. The spheres were sealed in, and the exposed face is flat and smooth.

To make this structure especially effective, use was made of transparent spheres or beads of index of refraction at least 1.15 times that of the overlaying covering sheet. Better optical properties resulted when the factor was 1.30. The spacing relation of the back reflector also was important and dependent on the refractive ratio. Rays entering the front of a bead converged at a point back of it. Empirically this had been found to be 0.575 times the radius of the sphere. The actual distance also depended on the refractive index ratio. In Table I is shown the relation between refractive index ratio and spacing distance.



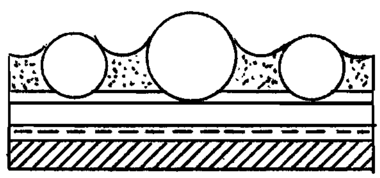


FIGURE 4. EXAMPLES OF RETROREFLECTIVE SHEETING IN CROSS SECTION(38)

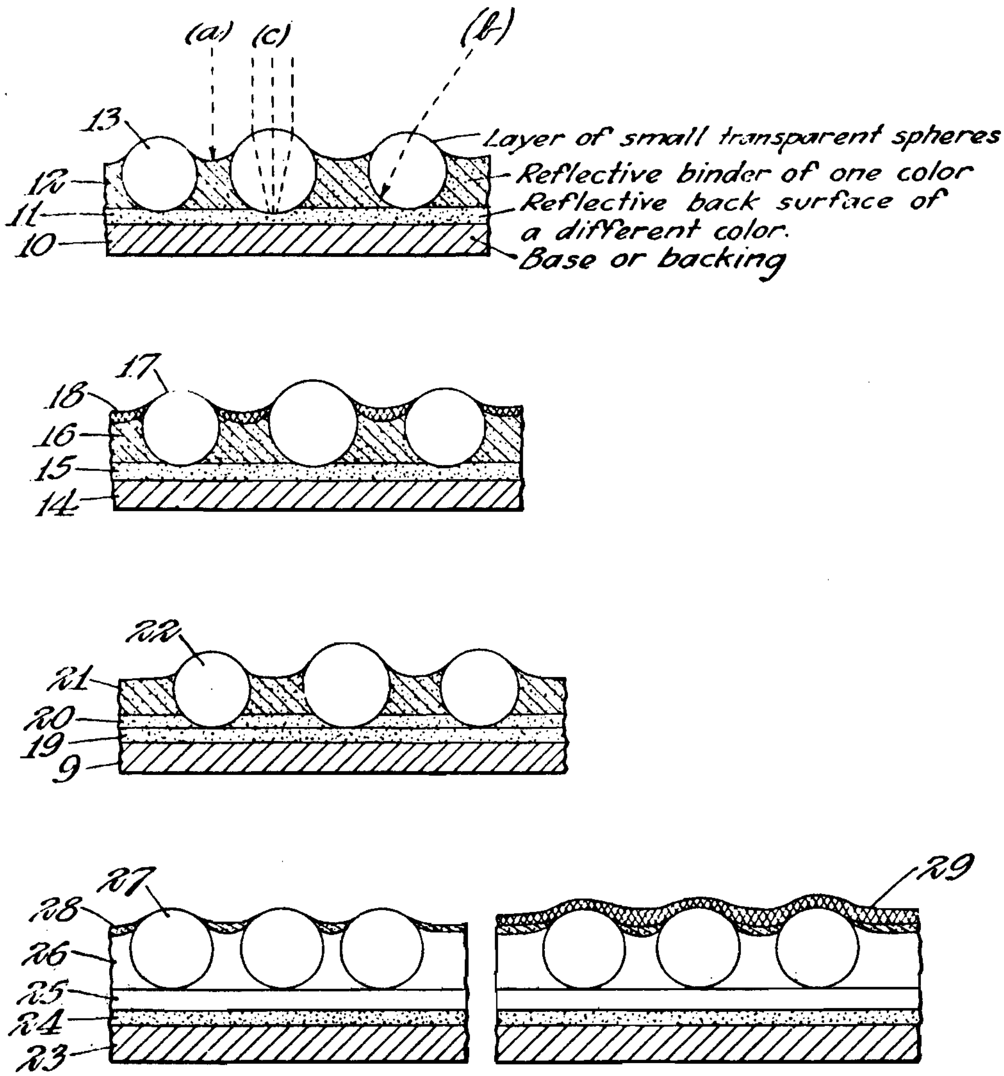


FIGURE 5. REFLECTIVE SHEETING HAVING DIFFERENT APPEARANCES AT NIGHT AND IN DAYLIGHT

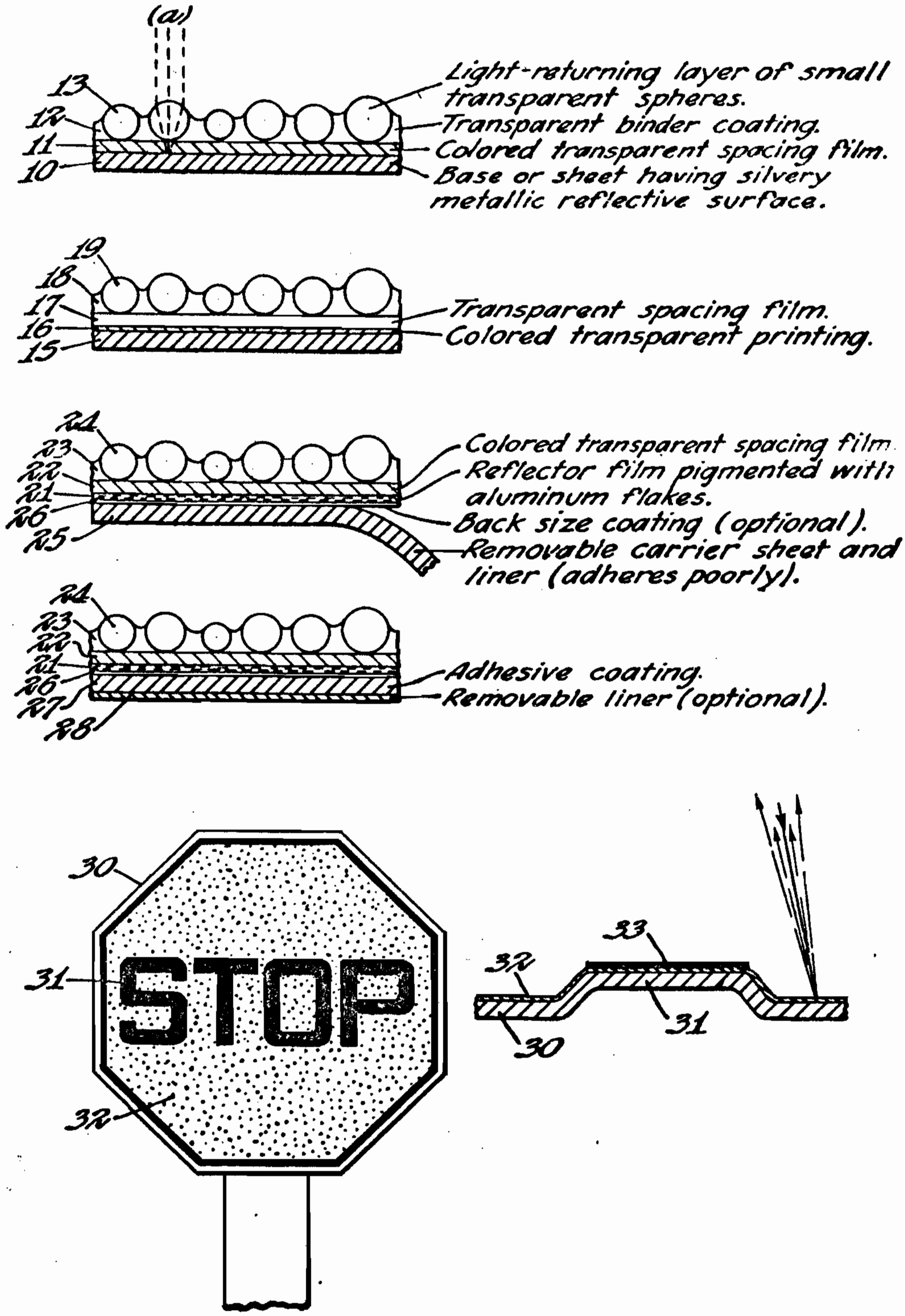


FIGURE 6. COLORED BEADED REFLEX-REFLECTIVE SHEETING[41]

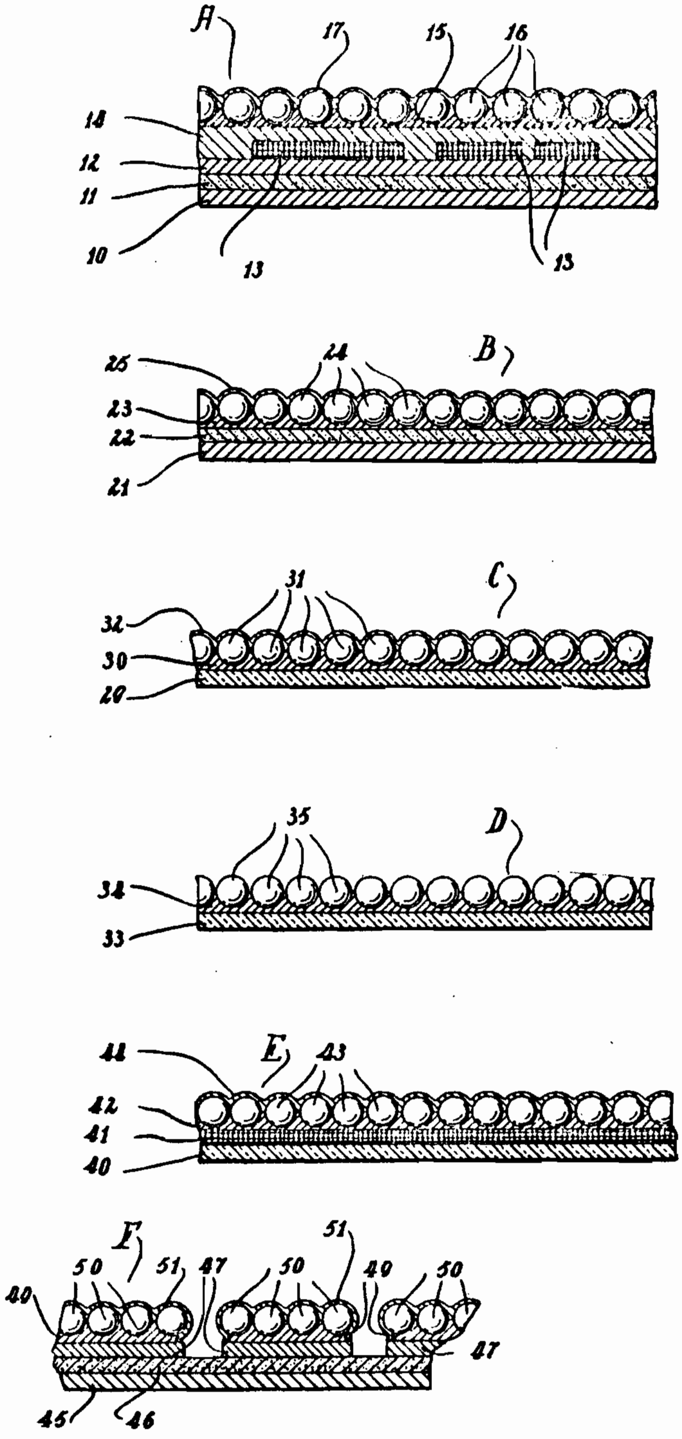


FIGURE 7. BEADED TRANSFER SHEETING OF THE TRANSFER DECALCOMANIA TYPE[42]

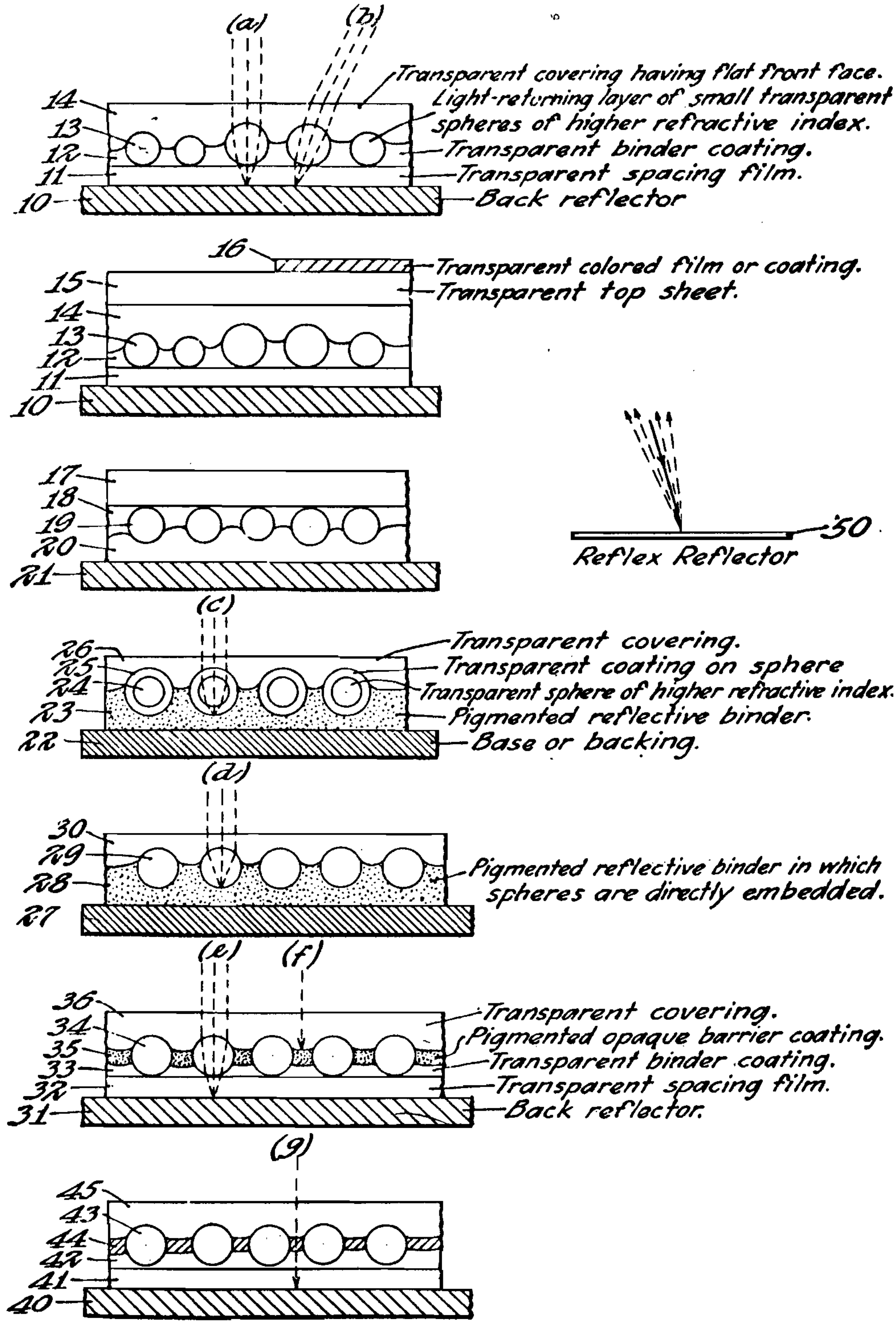


FIGURE 8. CONSTRUCTION OF "FLAT TOP"
BEADED REFLECTIVE SHEETING

TABLE I. EFFECT OF REFRACTIVE INDEX RATIO ON DISTANCE OF BEADS FROM THE REFLECTIVE BACKING

Refractive Index Ratio	Spacing Distance (Percent of Sphere Diameter)
1.02	1000
1.05	395
1.10	180
1.15	110
1.20	80
1.30	45
1.40	28
1.50	18
1.60	11
1.70	6
1.80	3
1.90	0

Beaded transfer decalomania or transfer label sheeting is illustrated[44] in Figure 9. The gummed label concept was used so that numbers, letters, or symbols and the like could be formed from reflective buttons or beads, stuck to the gummed label and the whole unit stuck to a suitable base.

Pressure-sensitive adhesive-backed sheeting for outdoor use is shown in Figure 10. This material was so formulated that it could be stretched or curved to form or conform to irregular outlines without buckling or gathering[45]. A method of greatly improving the anchorage of glass beads in retroreflective sheeting was described by Heltzer and Clark[46] and is illustrated schematically in Figure 11. High intensity colored reflex-reflector sheeting or tape with adhesive backing[47] was prepared as indicated in the sketches in Figure 12. A modified type of colored reflex-reflector sheeting and tape is shown in Figure 13[48]. This development was based on the discovery of the reflection characteristics produced by a layer of tiny transparent spheres with a refractive index of 1.9 when partially embedded in a reflective binder layer composed of a transparent film containing a mixture of tiny aluminum powder flakes and a transparent color pigment.

A reflector has been described[49] that appears black when viewed by daylight but has a brilliant silvery appearance when viewed at night under reflex-reflecting conditions. The invention was based on the

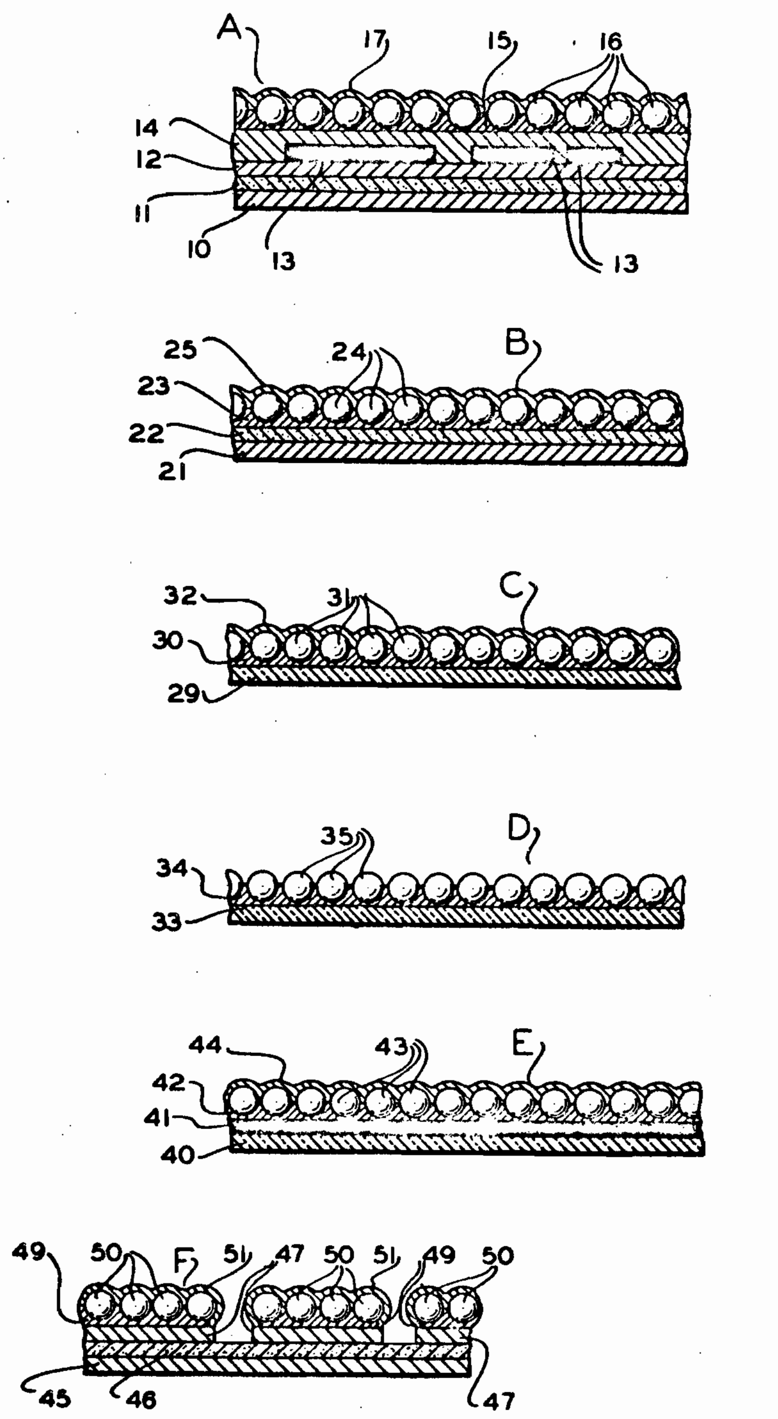


FIGURE 9. FLEXIBLE SHEETING USED TO FORM LETTERS OR SYMBOLS BY STICKING THEM TO PERMANENT BACKING

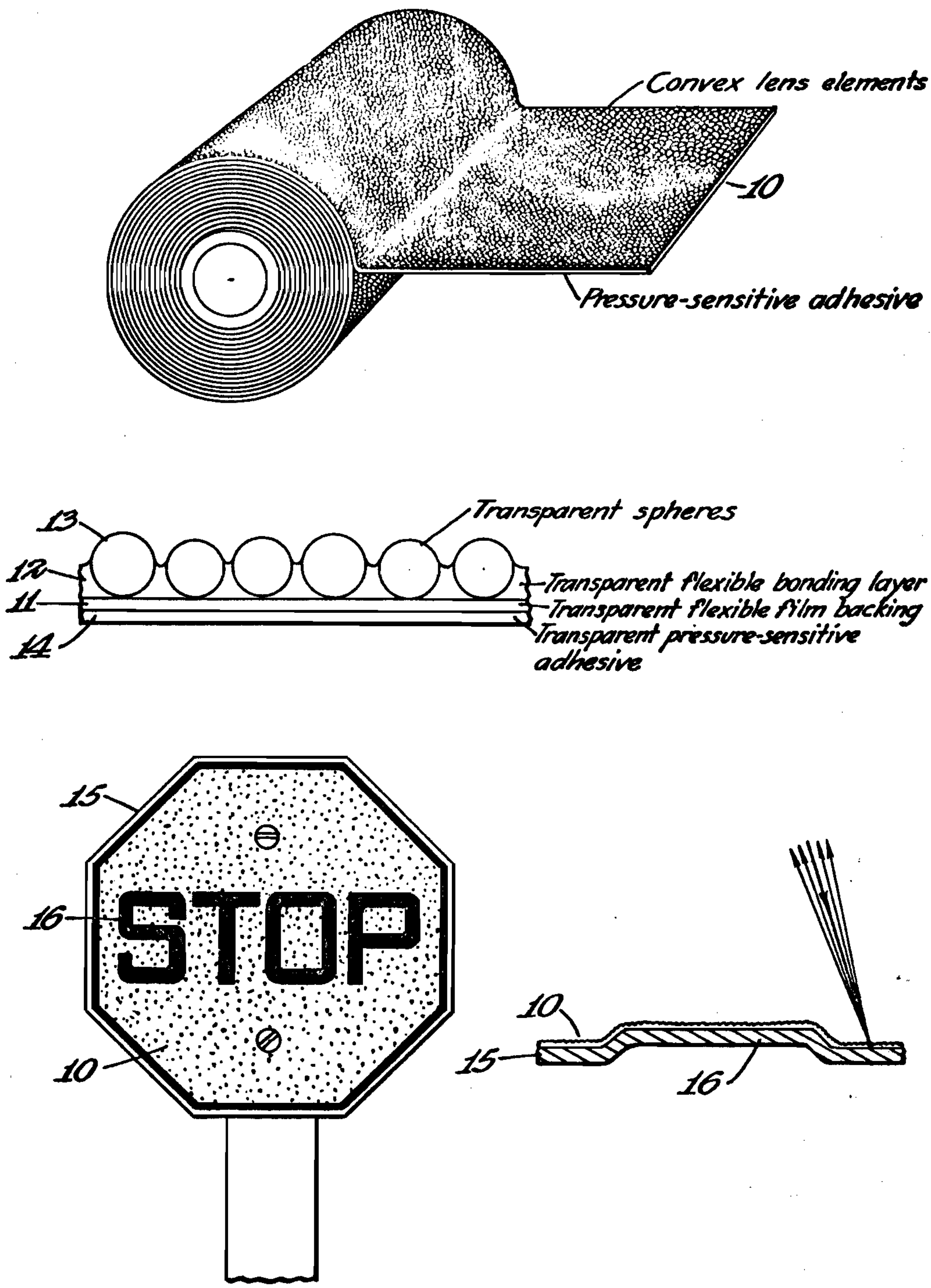


FIGURE 10. NONBUCKLING AND NONWRINKLING SHEETING AND TAPE WITH PRESSURE-SENSITIVE ADHESIVE BACKING

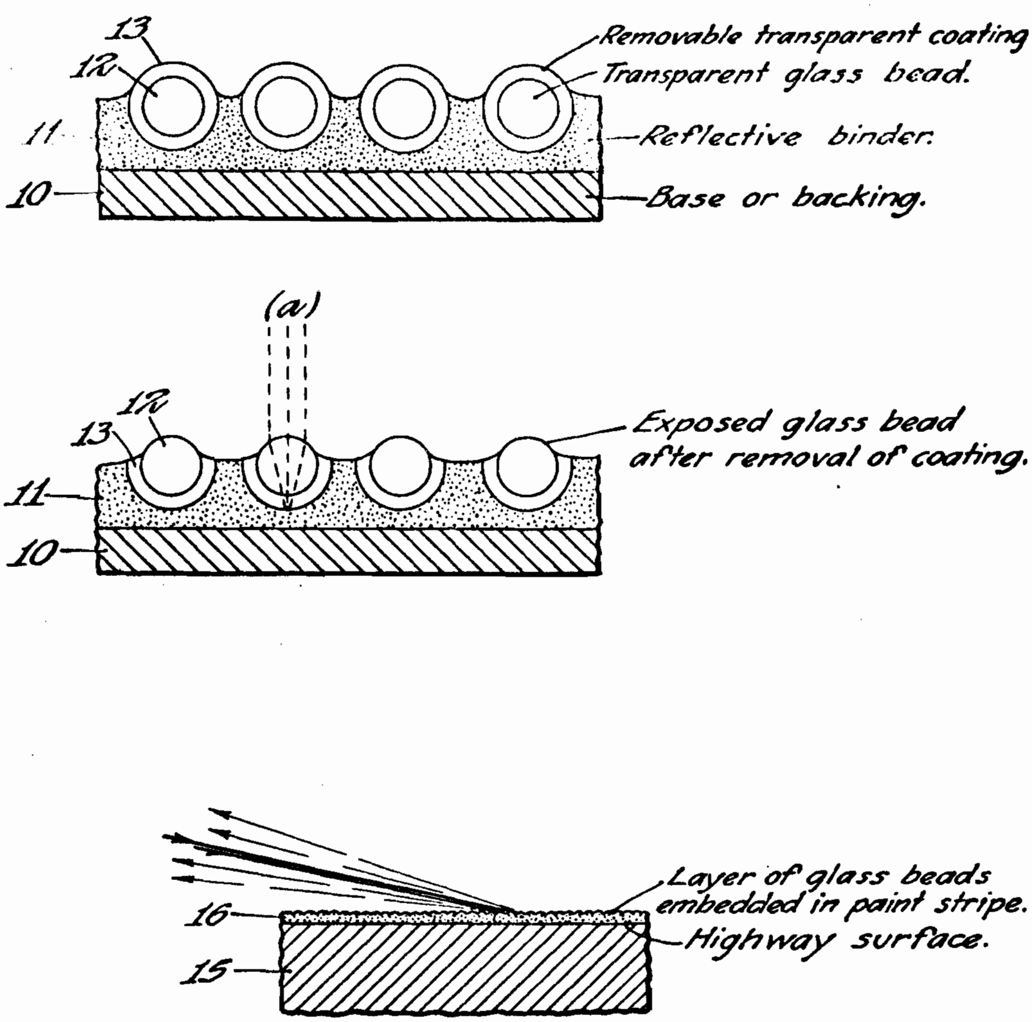


FIGURE 11. A METHOD OF IMPROVING THE BONDING OF GLASS BEADS TO ITS MATRIX IN RETROREFLECTIVE SHEETING[46]

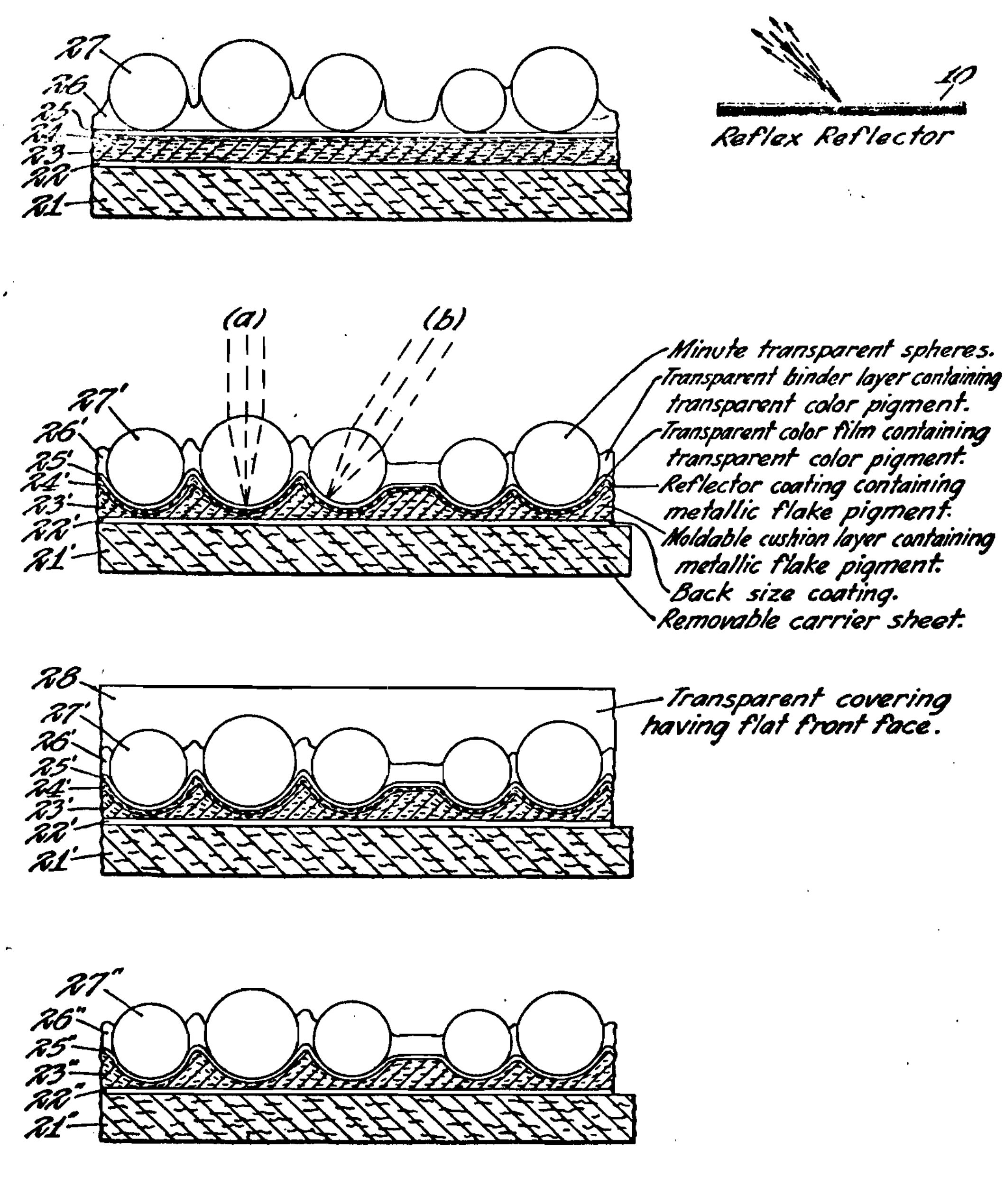
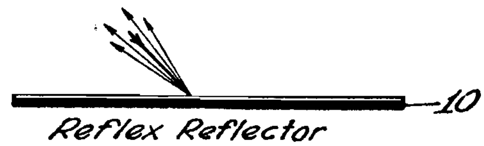


FIGURE 12. RED REFLECTOR, BEADED SHEET AND TAPE OF HIGH INTENSITY AND BRILLIANCE, SHOWING BOTH OPEN AND FLAT TOP TYPES



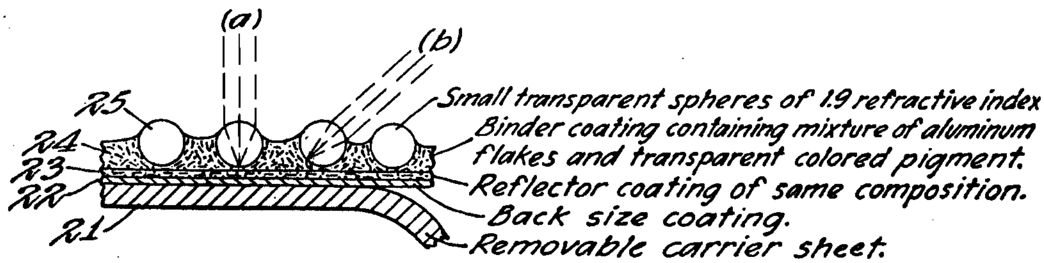


FIGURE 13. A COLORED BEADED REFLEX REFLECTOR USING A REFLECTIVE BINDER MATRIX[48]

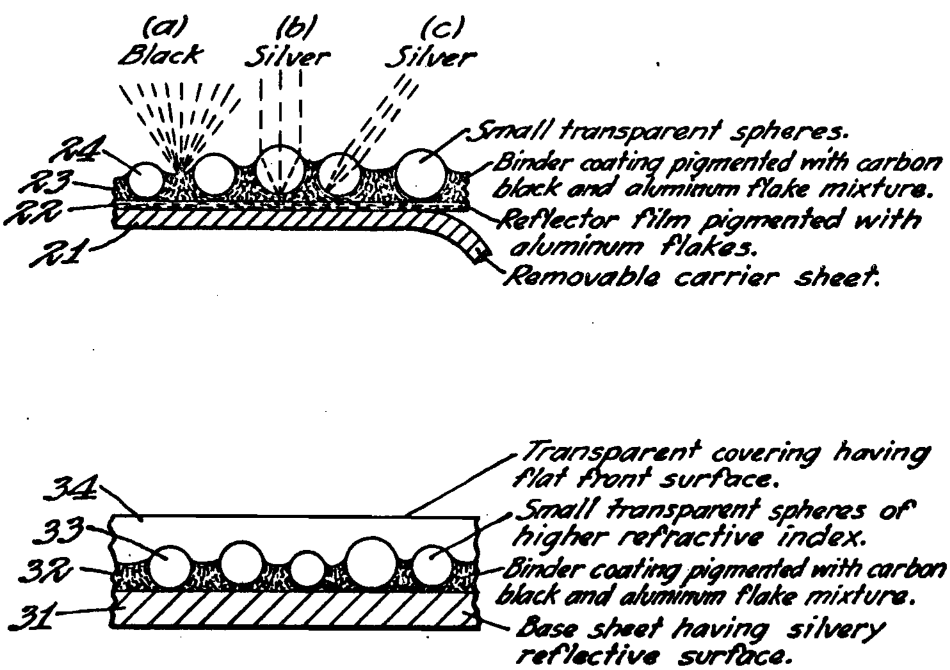


FIGURE 14. A BEADED REFLEX REFLECTOR THAT APPEARS BLACK IN DAYLIGHT BUT HAS A BRILLIANT SILVERY APPEARANCE UNDER NIGHT REFLEX-REFLECTING CONDITIONS

use of a layer of glass beads partially immersed in a binder pigmented with a mixture of carbon black and aluminum flake. A cross section is illustrated in Figure 14.

Porth [50] made reflectorized sheeting using the decalcomania concept. A temporary backing (paper) was coated with ethylcellulose or glue as a temporary carrier in which beads were embedded. This was applied over a permanent backing coated with a permanent binder, using the screen-printing process. The temporary binder was dissolved after the carrier had dried.

Light reflectors with a catadioptric structure employed small glass beads partially embedded in a reflective binder layer[51]. The construction of the facing was as follows: (1) a highly calendered, hard surface paper was knife coated with a 40% solution of isobutyl methacrylate polymer in xylene; (2) when dried, this then was knife coated with a 10% solution of polyvinyl butyral polymer in ethylene glycol monethyl polymer to a wet weight of 20 grains per square inch, then dried and coated with 12.5% of polyvinyl butyral polymer and 4.2% of tritolyl phosphate plasticizer in the same solvent; (3) the back reflector was cast with 12 - 14 grains per square inch of a solution of a thermosetting urea-formaldehyde resin containing a volatile solvent, castor oil, ethylene glycol monethyl ether selected pigment, and pigment grade aluminum flake; (4) this was dried and coated again with the same material as (3); and (5) while (4) was still wet, glass beads of 5 to 7 mils diameter and an index of 1.9 were applied in a single layer.

A reflex-reflecting sheeting was invented by Nordgren[52], the cross section of which is illustrated in Figure 15. With this sheeting, the legend markings are visible to an observer viewing the front face under daytime diffuse lighting conditions, but is visibly indistinct when viewed under illuminated reflex-reflecting conditions.

A reflective dry strip transfer sheeting was patented by Berg[53]. The cross section is shown schematically in Figure 16.

de Vries[54] was awarded a patent on reflex-reflective sheeting having the structure shown in Figure 17. This sheeting has a monolayer of glass beads completely embedded in a layer of transparent binder.

A pattern light reflector composed of a nonpatterned reflective backing is illustrated in Figure 18, as described in a patent by Alverson[55].

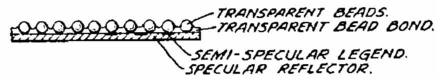


FIGURE 15. TAMPER-PROOF MARKINGS FOR REFLECTING STRUCTURES

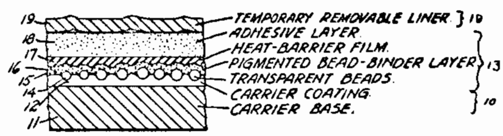


FIGURE 16. REFLECTIVE DRY STRIP TRANSFER

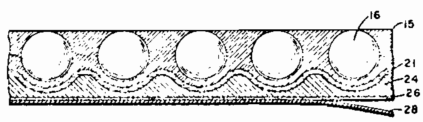


FIGURE 17. REFLEX REFLECTIVE SHEETING AND METHOD OF MAKING SAME

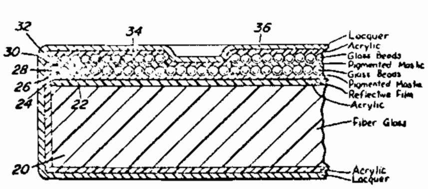


FIGURE 18. REFLEX SIGN

A description of "Scotchlite" manufactured by Minnesota Mining and Manufacturing Co., containing an adhesive back and a surface-reflectorized with glass beads, was given by Wagner[56]. Molded acrylic sheets with 2900 lenses per square inch molded into the surface makes reflecting signs with some advantage over glass buttons. This material is known as Reflexite[57, 58].

2. Glass Beads

Solid glass spheres were made by Davis and Heltzer from selected sizes of crushed window glass[59]. In this process, 1000 parts of crushed glass grain was mixed with 2 parts of carbon black, 180 parts of charcoal dust and 7.5 parts of water. This mixture was heated in trays or in a rotating furnace 1700 to 1800°F. The beads were 25 to 35 mils in diameter and had a refractive index in the range of 1.51 to 1.53. Such products were improved[60] by using only ash-free carbonaceous material and by a final washing with detergent solutions containing $Na_2P_2O_4$, NH_4Cl, soap and pine oil. Special compositions including borosilicate and phosphate glasses also were converted into small spheres. A similar process was used in Russia perhaps 2 years earlier[61]. An apparatus for producing glass beads was described in a Japanese patent[62].

The literature contains references to the compositions and refractive indices of beads for reflectorized highway signs and for pavement marking. A few references will be included here as illustrations of the kinds of materials used in signs in order to better understand their possible behavior during use.

For example, Beck[63] prepared beads with an index of refraction of 1.6 having the following composition: SiO_2 -22.9, Al_2O_3 -17.2, MgO -11.3, CaO -13.7, BaO -9.1, B_2O_3 -9.0, P_2O_5 -4.4, Na_2O -6.4, ZrO_2 -2.5, and CaF_2 -3.5 percent, respectively. Searight and Alexander[64] prepared glass beads with a refractive index in the range of 1.5 to 1.6, having the following composition: SiO_2 -65, Na_2O -14, CaO -14, BaO -6.3, and F_2 - 0.7 weight percent, respectively.

Rindone[65, 66, 67] prepared high index glasses of unusual composition, for example:

Oxide Constituent	Amounts, Mole Percent			
	Ref. 67	Ref. 66	Ref. 65	
SiO_2	- -	11.9 - 26.9	20 - 33	30.7
TiO_2	35.6 - 37.0	20.1 - 40.1	30 - 50	45.7
BaO	22.8 - 40.0	15.7 - 20.7	<32	3.5
PbO	- -	7.3 - 12.3	<26	10.6
K_2O	- -		<9.5	9.5
As_2O_3	- -		<1	
ZnO	0 - 20.0			
B_2O_3	5.5 - 26.9			
$AsO_{1.5}$		0 - 15.0		
$SbO_{1.5}$		0 - 15.0		
Refractive Index	$\geq$1.9	$\geq$1.9	1.9	1.93

Some publications have dealt with properties of beads for signing and marking. A study was made by Lyon and Robinson(68) of the chemical and physical properties of available glass beads. Criteria to judge the applicability of the beads to highway paints were used. Gumprecht and Sliepcevich(69) discussed the theoretical aspects of the optical properties of transparent spheres. They were mainly interested in light-scattering phenomena of possible use for particle size determinations. A patent has recently been granted to Robinson(70) dealing with a furnace for making signing beads. A feature of the design is improved control over quality factors such as size and shape.

3. Retroreflective Paint

Many highway signs and markers are based on retroreflective paints. These could be of two types: (a) a good coating of paint applied to the backing material (plywood, wood, steel or aluminum) and one layer of glass beads applied to a second paint coat while it is still wet or tacky or (b) a paint which contains, as an essential part, a filler of reflective material, usually beads.

For reflective signs, the usual practice is to develop formulations using mixtures of conventional paint materials. A common practice is to use such formulations and bond a surface layer of beads. Information on paints for signs does not seem to have been collated and published extensively.

Some bead-bearing paints are produced. Most of these apparently are made for use for marking on pavements. Some retro-reflectives are commercially available, but not much has been found concerning them in the literature.

The subject of paints, per se, is very extensive and complex, and will not be extensively discussed. Where paints are used, they are selected, applied and used under the guidance of professional paint chemists. Formulations which may be proprietary are compounded from commercial paint materials in accordance with highway specifications.

The term "paint" is a broad, nonprecise term. In general it refers to suspensions of solids in liquid vehicles that are applied to existing structures and caused or allowed to dry. For highway signing, in many instnaces the term "coatings" might be more applicable were it not for the fact that the base materials used, and the process of application, are or may be the same as for paint.

The complexities of paint formulation and paint behavior are seldom realized except by those engaged in their manufacture or their evaluation. Basically a paint is a careful integration of selected pigments with liquids known as vehicles, otherwise known as oils, binders, vehicles, thinners or varnishes. The service the paint is expected to perform dictates the choice of the materials.

Highway signing employs special paints that would be classified as for outdoor service. The primary components may be divided into pigments, vehicles and drying agents. The pigment portion may be subdivided into primary, modifying and extenders.

There are other types of paints called emulsion paints. These contain an emulsion of two phases, one of which is water, and one or more other liquids that may be an oil, resin or varnish. Latex paints are rubber-like materials in which the dispersed phase is a plastic semisolid that forms a "latex" rather than an "emulsion." Styrene-butadiene copolymers, polystyrene in either post- or preplasticized systems and polyvinyl acetate emulsions are most commonly used.

There is very little in the literature concerning paints specifically for highway signs. Several authors, however, discussed traffic paints and paints for use on pavements and roads. This field is regarded as beyond the scope of the present task. Wiederhold(71) discussed weatherproof afterglowing paints based on the use of ultraviolet-reflecting substances and fillers that will not absorb water. Palmquist(72) made a retroreflective paint that could be used on selected backing materials, primarily on flexible sheet material. In his process, cloth or flexible sheeting was treated with a sizing material, then with a layer of adhesive to which a top layer of glass beads was spread.

K. K. Moore and C. B. Hastings(73) discussed in some detail the importance of paint-hiding power and bead index of refraction on the reflectivity of beaded highway signs. This report contained a great deal of important detail, but was summarized as follows: "This report covers the effect of two variables encountered in producing high quality beaded highway signs.

"First is the effect of the index of refraction on retrodirective reflection. This work confirms the idea previously expressed by others that there is an optimum index of refraction for the maximum reflectivity obtainable from beaded signs, and that it is in the neighborhood of 1.92.

"Second is the effect of hiding power of the paint on retrodirective reflection. It has been found that the hiding power of both the binder and the paint directly under the binder has a great deal of effect on reflectivity. If the hiding power of both paints is increased to an optimum, then the reflectivity can be increased by about 60% over that which is now being obtained from the present highway signs made with materials currently specified."

4. Reflector Buttons

Reflector buttons are individual reflecting units arranged in rows or patterns to form letters, symbols or borders. They give the visual impression of continuous lines or areas of light when used in suitable sizes and with suitable spacings. The reflectors may be made of glass or transparent plastic with molded-in lenses or prisms designed for retrodirective reflection(74). Delineators are usually made of reflective buttons(75). For letters, symbols, numbers, etc., buttons are permanently mounted in metal strips that can be assembled to form the desired effect using screws or bolts.

Neal(76) studied the size, arrangement and colors, and the correct location of arrows for highway signs. The effects of source and receptor dimensions on retroreflective properties were measured and compared with laboratory tests(77).

Weber(78) is credited with the design of a new brilliantly-reflective, wide-angularity, reflex-reflecting device. This combines the retroreflective bead principle with cube-corner retroreflective units as shown in Figure 19.

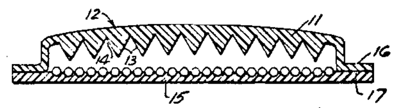


FIGURE 19. REFLECTOR BUTTON, WITH BOTH BEADS AND PRISMS

5. Fabrication and Manufacturing

Several general types of reflectorized signs are manufactured by and for the Texas Highway Department(79). These are based on the use of (a) beaded paint, (b) retroreflective sheeting; (c) retroreflective buttons, and (d) combinations. Manufacturing practice using beaded paint was described in a Texas Highway Report(80), pages 7 to 15. Figures 7 through 13 of that report show the process sign blanks follow from the time they are received until they are ready to be placed on the road as a finished sign. The sign backings may be plywood, steel or aluminum. The backing is cut to the specified size and shape, and cleaned. This then is run through an automatic spray machine to apply the primer coat. When this is dry, it is sprayed again with the reflector coat, run through the bead spreading machine, and then put on racks to dry. The message is stenciled on by a silk-screen process and by using adhesive retroreflective sheeting cut to the required shape for letters, symbols, numbers, or borders(79). The finished signs are stored for future use.

Signs are made from reflectorized retroreflective sheeting. There are two types: open bead and flat top. Figures 14 through 19 show some of the steps in the fabrication of signs with plastic beaded sheeting. Steps not shown(79) are the reclaiming of old signs and the cleaning, pickling and plating of the steel backing, followed by the application of the message and background in the form of adhesive retroreflecting sheeting. Texas reflectorized signs and their preparation were first described in 1947(81).

The manufacture of reflecting signs in Germany in 1951 was described by Diebold(82), where reflecting colored paints were applied to sheet steel. Operations, layout and manufacturing activities of Detroit highway shop have been described by Gibson(83), and the methods used by the Mississippi State Highway Department were described by Chambliss(84).

6. Specifications and Tests

This section is concerned mainly with specifications and some tests for retroreflective sheeting, paints and beads.

Some good information may be found in the German literature. Jainski[85] discussed in some detail methods for testing the suitability of reflector materials for traffic signals. This article does not add much that is new and deals with the effects of angle of incidence, and the effects of white, silver, red and yellow reflectors. German specifications for route markers on highways and provisional rules concerning the quality of materials were published by Albrecht[86].

Sign standards for Interstate Highways such as lettering, color, reflectorization and other parameters were discussed by Eliot[87]. This was not a very detailed presentation. Although most of the paper dealt with problems outside the scope of this section, Reference 88 presented an interesting guide to the preparation of purchase specifications. E. Warner[89] published one of the better and more complete articles on the characteristics of sign paints, colored reflectorized signs and marking devices. This article, too, was based on somewhat quantitative information.

Related information on paints may be found under such subjects as:

(1) Understanding the mechanisms of deterioration of paint[90].

(2) Causes for discoloration of paint[91].

(3) Exposure studies of organic pigments in paint systems[92].

(4) The physics of paint films[93].

Pertinent specifications for Texas Highway Department are referred to in Appendix I. Other specifications are listed in Appendix II.

C. Nonreflectorized Surfacings

1. General Characteristics

Nonreflectorized signs are made with either matte or glossy surfaces. When illuminated with exterior light sources, the former tends to exhibit diffuse reflection and the latter, specular reflection. Signs may be illuminated or nonilluminated, and may be surfaced with paint, plastic or porcelain enamel. The painted ones and those surfaced with plastic may be backed by wood, plywood, steel or aluminum. Most porcelain enameled signs now are on aluminum, but some are on steel.

2. Plastic Signs

Vinyl surface sheeting has been advocated[94] that could be pressed against smooth surfaces and then strongly adhere without the use of glue or adhesives, and still be readily removed by peeling. Strip-type vinyl coating in liquid form sprayed on the surface of backing materials and air dried to form abrasion-resistant films has been successfully adopted as a masking material for painting formed acrylic signs[95]. The use of plastics for highway signs was reputed to result in improved weather resistance and lower maintenance costs because of their ability to absorb abuse[96].

3. Porcelain Enameled Aluminum

Signs. Porcelain enameled aluminum for highway signs was discussed by Angelini[97] and Cysewski[98]. The fast growing acceptance of extruded aluminum sign panels has continued since they first were used on the Ohio Turnpike. Menking[99] discussed the properties required in extruded panels as well as erection methods. The signing system in Tulare County, California[100], where a uniform specification was adopted calling for either porcelain enamel, or aluminum and reflective sheeting for all signs is said to have been highly successful.

Fabricated porcelain enamel on aluminum signs with white message copy on dark green background was described by Crosby[101] for overhead signing. Over 65% of aluminum signs damaged by motor vehicles on the Ohio Turnpike were repaired by cutting damaged extruded ribs, straightening with a hydraulic jack and then reinforcing with aluminum bars[102]. Several types of signs and markings as used by Virginia Department of Highways were described by Bullock[103].

Aluminum Enamels. A summary of the characteristics and properties of aluminum porcelain enamels, and their processing, is necessary as a basis for understanding signs faced by it. Aluminum enamels generally are thinner than enamels for steel, being in the range of one to three mils per layer. This is compared to modern titania-base coatings on steel, of 6 to 8 mils, which is only 1/4 to 1/3 of the thickness of ordinary porcelain enamels on steel. These thin coatings on aluminum improve their resistance to impact[104], thermal shock and torsion. The thin layer also makes differences in thickness of minimum importance. Thin coatings, however, are somewhat detrimental to maximum surface hardness. Enameled aluminum panels can be sheared or cut without visible chipping or cracking, and raw edges do not require protection.

A review of the development and techniques of aluminum enamels was published by Huppert[105]. He[106] also described the processing and manufacturing techniques, including required surface treatments prior to enameling.

The effects of raw materials on the physical properties of aluminum enamels was discussed by Kautz[107]. Giles[108] summarized standard test procedures for chemical, mechanical and optical evaluations used in the porcelain enamel industry. The purpose and application of these tests are to aid the engineer in specifying enamels for specific applications.

Coffeen[109] prepared a bibliography in 1957 covering the entire literature on enamels prior to that date.

Compositions and processes for the preparation of enamels on aluminum and its alloys were summarized by Thomas[110]. Porcelain enameled aluminum foil and sheet is mass produced in a wide variety of colors and in finishes ranging from high gloss to matte[111]. Properties, production and surface condition of porcelain enameled aluminum were summarized by Farrell[112]. Huppert[113, 114] presented a history of aluminum enamels and details of current methods of application, including electrostatic spraying and roller coatings, and Kautz[115] discussed enamel shop problems.

Descriptions[116, 117] of modern and automated enameling plants help to understand the limitations and materials problems to be expected. Defects and methods of repairing them were discussed by Forwith[118] and by Herbst[119].

The enameling of a variety of light alloys, from magnesium to aluminum, has been widely discussed; for example, by Stradley[120], Lister[121] and DeLong[122]. Stripping of enamel from aluminum, called de-enameling, also reportedly has been successfully accomplished.

The composition of aluminum enamels, being considerably different from that of enamels on steel, or of glass or glass beads, also is of interest. Examples of compositions are to be found, for example, in articles by Kautz[115] and by Brinker[123]. One composition is, in mole percent, PbO - 6.2, SiO_2 - 36.3, TiO_2 - 19.5, Na_2O - 23.4, Li_2O - 5.6, K_2O - 4.8, Sb_2O_3 - 0.6, B_2O_3 - 0.1 and BaO - 3.5.

Manufacturing. The manufacturing of porcelain enameled signs was discussed by Jones[124] and by Malec[125]. The techniques include spraying, stenciling, silk screening and transfers. It is interesting to note that small dimensional changes occur in aluminum alloys during heat treatment by enameling[126]. The change is not very predictable, but is influenced by alloy composition, temper of the metal, metal thickness and enameling variables.

Tests and Properties. Havens(127) has described an ingenious method for determining the flatness or waviness of porcelain enamel panels. A slope indicator was used that was capable of measuring the slope or buckle at any point. Low gloss materials with slopes up to 2% may be visually acceptable. Permissible slopes for materials of higher gloss were less.

The weather resistance(128) of panels representing 14 types of enamels on iron was evaluated after 15 years exposure at Washington, D.C., St. Louis, Mo., Lakeland, Fla., and Atlantic City, N.J., was evaluated. Changes in gloss and in color were taken as criteria for weather resistance. With but few exceptions, there was a direct correlation between acid resistance and weather resistance. A modified acid-resistance test was devised that separated red enamels, showing pronounced fading, from those that were highly resistant to color change. The ease of cleaning was related to weather resistance. With but few exceptions, the climates at the various exposure sites had only a minor effect. Although these data are not on aluminum enamels, the testing process and the general conclusions are useful for aluminum signs.

A computer(129) was used for reducing this large mass of data accumulated in the P.E.I.-N.B.S. outdoor porcelain enamel weathering test. The gloss index was computed and averaged for four positions on each specimen. The color stability index was computed from the equation $I_{cs} = 100 - \Delta E$, where ΔE was the color change in N.B.S. units. In addition, the program was arranged so that the computer would calculate averages for sites, grand averages for the same enamel for given sites and the standard deviation of the averages.

Tests of aluminum enamels for acid resistance, adherence, reflectance, gloss, resistance to torsion, resistance to gouging, abrasion and thermal shock according to Porcelain Enamel Institute test methods were described by Giles(130), Meyer(131), Kerstan(132), and Plankenhorn(133). Special tests have been reported by Stradley(120), Dietzel(134), Giles(130), Meyer(131), Huppert(135), Biechler(136), Moss(137), and Sopp(138). Included are various service properties (but not highway signs); torsion, scratch and abrasion resistance, mechanical properties, chemical durability, weather resistance, color fastness, and staining.

Chemical durability and weather resistance, including stimulated service condition tests, have been extensively studied. Direct observations on the effects on aluminum enamels of exposure to weathering, sea water, and several other chemical solutions were made by Biechler(136). Corrosion studies of enamels on steel were made by Priest(139) in order to better understand the mechanisms and characteristics of enamel corrosion in relation to their service behavior and to testing methods. Neither this study nor the exhaustive weathering test of the National Bureau of Standards[128, 129] was conducted on aluminum enamels nor oriented toward highway signing. They, nevertheless, provide information that is useful in orienting weathering studies for highway signing. Accelerated weathering tests employing boiling citric acid or boiling sodium pyrophosphate solutions were conducted by Sopp[138] on aluminum enamels.

Standard Tests and Specifications for Aluminum Enamels. Porcelain enamels on aluminum are well provided[140] with standard tests, standards and specifications. These are listed in Appendix I and in Appendix II. Specifications of Texas Highway Department are given in Appendix I. Other tests, standards and specifications are listed in Appendix II.

4. Illumination

This subject, while having a bearing on the problem of non-reflectorized signs, is of a low order of priority. In this literature study, only the references themselves will be included. Pertinent articles are listed in the "List of References" as numbers 141 to 150 inclusive.

5. Paint

The subject of nonreflectorized paint will not be treated in this report.

D. Unconventional Materials

Fluorescent and phosphorescent materials may in the future become important as sign facings. At present, however, they are not important. A few references will be cited as examples.

Nuclear energized self-luminous highway signs were advocated by Williams[151]. He would employ isotope-activated phosphors. He visualized that visibility might be increased from a few feet to as much as 2000 feet. Metal-based electroluminescent lamps with ceramic dielectrics are less moisture-sensitive than glass or plastic lamps. The ceramic coating could be a mixture of phosphor and frit which would be overcoated with a solution of tin chloride to make a transparent electrode.

The literature is rich in information on luminescent, fluorescent and electroluminescent materials[152]. Electroluminescent porcelain enamel was described by Vincent[153], and Kerstan[154] described fluorescent porcelain enamels. An electroluminescent vitreous enamel was patented by Hoffman[155].

E. Summary of Literature on Sign Legibility

This subject recently has been reviewed and condensed by Forbes, Snyder and Pain(156). A summary of the report follows: "Published reports for 10 years were systematically searched for studies of factors affecting highway sign effectiveness. Attention-gaining characteristics proved to have been relatively little studied compared to legibility, but were indicated to be of equal importance. Most of this subsection refers to signs in general and is not restricted to reflectorized facings.

"Analysis of the driving task indicates the importance of multiple response tasks in measuring attention-gaining characteristics. Further on the latter is planned."

In preparing that report, 397 titles were reviewed, of which 211 were considered pertinent and checked further. Of these, 110 were read and abstracted. The report cites 41 references, plus source Report Titles including the following:

Highway Research Board Proceedings 1953-63.
Highway Research Board Bulletins, especially
Bulletins of the Night Visibility Committee.
Psychological Abstracts.
Traffic Engineering.
Journal of Engineering Psychology.
Human Factors.
Review by Desrosiers - (unpublished).

An extensive report was prepared by Richard D. Desrosiers(157), pertaining to highway destination signs. This report was the result of a library survey and was dated August 1962. This review was based on and cited 37 references. The main topics discussed were letter size, spacing, width, and height; reading time, color, size and shape of sign, sign configuration, illumination and reflectorization, and location.

Legibility and letter standards were established by Forbes and Holmes(158). The results of this work have led to wide acceptance and standardization with respect to legibility in relation to letter height, width and spacing, for highway signs of all kinds.

Hastings and Moore(159) made a study of beaded red stop signs. This report was the result of original Texas Highway Department research and covered both theoretical and practical aspects of red beaded signs.

There are a number of different functional types of signs; regulatory, warning, guide, and miscellaneous signs and markers. These, as well as alphabet details for Texas highways, are covered by a manual on uniform traffic control devices(160). Detailed sign designs are contained in a manual prepared by U. S. Bureau of Public Roads(161). A manual containing specifications for a uniform system of traffic control devices, regulatory signs, warning signs, guide signs, markings, signals, and all pertinent and related subjects was issued in 1954(162).

Further details regulating and specifying signs, including visitor information, center signs, special situations, reduced size hazard markers, changeable message signs, interchange delineation, use of flashing beacons, and all other pertinent cases are defined in Texas Highway Memos(163).

A comprehensive treatment of signing and traffic control devices is given in the Manual on Uniform Traffic Control Devices by the Bureau of Public Roads(74) and in the Manual for Signing and Pavement Marking by the American Association of State Highway Officials(75). Siegel(177) discussed five variables that can be controlled to make signs more effective. These were shape, color, location, spacing and illumination. Visibility of highway markings was discussed by Warner(89) with respect to color, shape and location, principally of pavement markings.

Suggestions for distinctive types of road markers were made by Burch(164). He advocated shapes and colors easily identified, recognized and interpreted. Color on route markers was adopted by the Mississippi State Highway Department and has been successful(84). Mills(165) reported on fatality statistics on eight representative turnpikes to determine the effectiveness of using reflective green backgrounds; four roads were marked with reflective background signs and four used nonreflective backgrounds. The conclusions were that reflective green backgrounds were effective in helping to reduce accidents.

The effect of letter width and spacing on night legibility was studied by Solomon(166). Using white reflectorized letters on a dark background, he found an optimum spacing between letters. In the design of signs, Webb(167) recommends that directional signing should be considered first. He detailed the principles to be considered in directional signing and outlined a correlation of geometric design with signing requirements.

Moskowitz and Moran(168) reported on tests made to settle a controversy regarding legibility of lower case lettering on highway directional signs in comparison with upper case lettering. The conclusions were that lower case lettering was slightly more readable than capitals.

III. PHOTOMETRY

The state-of-the-art of color measurements is still such as to cast some doubt on casually easy communication of accurate color descriptions between remote activities without prior preparation and agreement on standards between the two activities[169]. Even the generally accepted standard instrument of the industry (the GE recording spectrophotometer, described in some detail in Reference 170, pp. 83-91) has been routinely misused in such a way as to elicit concern among members of the Inter-Society Color Council. The results of a round-robin study of color measurement have led to comments such as "shocking" and "almost scandalous"[171].

In many cases a change of color is important only because such a change may be correlated (with varying degrees of accuracy) with the ability of a sample to withstand elemental attack of one sort or another. In other cases the color change itself is important due to the function or intended use of the sample. In the first instance only the most easily measured aspect of the color change may be sufficient for test purposes. For example, the change may be due to surface hazing (leading to decreased color saturation) in which case a simple gloss measurement may be indicated. In the second instance a true color measurement is usually indicated.

Color measurement of retroreflective surfaces requires close control of the instrumental geometry, as the retroreflective manifestation of color may not be the same as the color of such material when viewed under normal illumination. Indeed, some such materials are treated specifically to present a difference in appearance under the two methods of illumination.

A cursory examination of the spectrophotometric curve of a surface will usually not be very informative, except to a highly practiced observer, as to the color of the surface. Two curves that appear identical may represent two perceptibly different color shades[172], and at the same time it is possible to obtain decidedly different curves which represent colors that are visually indistinguishable from each other.

One of the advantages of spectrophotometric data derives from the possibility of interpreting the physical basis for a color difference; e.g., a surface degradation or weathering phenomenon may produce a characteristic family of changes in the spectrophotometric curve which could contribute to an understanding of the degradation mechanism.

Colorimetric methods applicable to signing may be roughly divided into two types or classes of color measurement as a function of the purpose of the measurement.

1. Compliance with acceptance specifications requires only that a submitted sample exhibit color characteristics that lie within specified bounds. A determination such as this is most practically and economically met by comparison with a standard sample using the appropriate ASTM method. The requisite characteristics of such instrumentation are high sensitivity but only a low order of built-in calibration, as the standard sample (along with color-pass filters and illumination source) serves as the calibration point. In this usage the unavoidable instrument inaccuracies affect only the difference between the sample and the standard, rather than being a fraction of the much larger full scale range of the instrument.

It may be noted that the above description qualitatively describes the capabilities of the normal human eye; however, the ability to quote instrument readings and avoid the vagaries of human judgment (even if highly trained) represents a viewpoint that is increasingly prevalent.

In general, the above class of color measurement may be performed with a reflectometer when suitable color filters and a standard illumination source are available. This capability is, of course, dependent upon the "tightness" of the specification and upon the geometry of the sample to be tested. It may be noted that nearly all present day specifications for color are written using the 1931 CIE designations. The system is internationally recognized and is capable of very accurate description; however, there is the distinct possiblity of allowing the fineness of the system to induce an unrealistic rigidity into the specifications so that measurement requirements may exceed the capabilities of economically available instrumentation. The CIE system is designed to divide the color solid into about five million divisions (about the same as visual discrimination) which requires a photometric measurement accuracy on the order of 0.1%. This accuracy can be expected from the Hunter multipurpose reflectometer; for instance, when matching between <u>close</u> pairs that are known to be nonmetameric and nonfluorescent. If a white (magnesium oxide or tile) standard is used, it is possible, with the same instrument, to have an uncertainty of 0.02 in x and y in the measurement of darker blue-green colors[173]. This uncertainty is the tolerance limit specified in the y coordinate in the Texas Highway Department Specifications for interstate green as applicable to porcelain enamel on aluminum.

2. Changes in photometric and color characteristics due to deterioration as a result of weathering or other aggressive degradation should be considered in the light of the stage of development of the test as applied to a particular category of sample material.

If a relatively unfamiliar or recent category of sample is to be investigated (that is, one with an insufficient or unsatisfactory background history of correlation between photometry and degradation) then data in the form of spectrophotometric curves are desirable in order to gain an insight into the mechanism of degradation and to determine the most appropriate photometric test method for subsequent routine or extended investigation.

If a category of sample with a well established history of correlation is to be examined, the published ASTM test methods are usually adequate.

Gross surface topography may be of some functional importance from two aspects; (1) the condition of a backing panel prior to the application of facing material, and (2) the condition of the combination after fabrication or after some exposure to field use or artificial environment. Elmendorf and Vaughn[174] discuss several methods of evaluation of smoothness; however, adaptation to field measurements is open to conjecture.

Hurd[175] describes an interesting photographic procedure that may have useful applications in devising fairly rapid and simple goniophotometric determinations of both retroreflective and diffuse surfaces. If Polaroid types of film can be adapated to the described method, a field determination becomes possible.

There have been some recent interesting developments in instruments of the telephotometric class in that the demand by photographers (both professional and hobby categories) has led to the introduction of a number of portable devices that appear to offer distinct possibilities for adaptation to sign brightness and contrast measurements in the field[176].

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PART TWO

FIELD INFORMATION

I. RESULTS OF QUESTIONNAIRE TO 50 STATES REGARDING HIGHWAY SIGNING MATERIALS

Purpose. In order to obtain some idea of practices of all of the states concerning highway signing materials, a brief questionnaire was prepared and circulated to 50 state highway departments. This information was needed in order to understand better the state-of-the-art on highway signing practice in the United States. In addition, it was possible to obtain and study many highway department specifications and thereby to understand objectively to what extent advanced specifications are in use and to what extent and in what particulars additional ones are needed.

Results. Fifty states were contacted and replies were obtained from 46 of them. The questions asked are shown in Table I, along with a summary of the answers. Considerably more information was conveyed than is shown in the summary in Table I. A detailed compilation of this information would not be very useful here. However, this information has been used in connection with making conclusions and recommendations.

All of the states have specifications dealing with signs and sign facing materials. Most states specified retroreflective materials as to brightness, but 13 of them did not specify as to durability.

A study of available specifications indicated that sign facing materials tended to be in terms of products rather than objective properties. Some highway departments apparently have adopted specifications originally prepared by sign materials manufacturers.

Specifications for highway signing were studied to ascertain their adequacy for the standardization of the many and varied individual state specifications. The AASHO Manual and other directives are issued as guidelines for signing; except for the standardization of the Inter-State System lettering and symbols, each state has made its own interpretations. In some instances the specifications as written tended to be broad but others tended to be restrictive.

The general contents of the specifications have been condensed and shown in outline form in Table II. Most of the state's specifications contained at least a minimum requirement on the primary and secondary elements, i.e., IA, IB, IC and ID. However, in a majority of the specifications, details were sketchy or lacking as to the tertiary elements, i.e., I. A. 5 (Durability), etc.

TABLE I. SUMMARY OF 46 REPLIES TO QUESTIONNAIRE

		Yes	No.
1.	Does your State Highway Department have specifications for materials for highway signs?	45	1
2.	Specifications for durability?	33	13
3.	Specifications for brightness?	45	1
4.	If answers to above are yes, will you send us a copy of respective specifications?	40	6*
5.	Do you purchase signs from commercial sources?	32**	13
6.	Does the Department maintain a laboratory for the following:		
	a. Sign research and development	11	34
	b. Sign materials testing and evaluation	25	20
	c. Maintenance serviceability	13	32
7.	Other information not included above would be appreciated.		

*Six states were rewriting their specifications and will send a copy when available.

**The majority of these 32 states purchase signs only for the Interstate System.

TABLE II. GENERAL OUTLINE OF AN "AVERAGE" SPECIFICATION ON HIGHWAY SIGNING

I. Materials for Signs

A. Reflective Sheeting

1. Photometric

a. Background
b. Applied or demountable copy
c. Brightness

2. Color
3. Adhesive
4. Film

a. Surface
b. Lens elements
c. Protective liner

5. Durability

B. Demountable Letters, Symbols

1. Acrylic plastic reflectors - Type A

a. Optical requirements
b. Testing procedure
c. Durability
d. Sampling procedure

2. Type B letters - white removable legends

a. Design - fabric
b. Reflectors
c. Optical requirements
d. Specific brightness
e. Reflector durability
f. Reflector sampling procedure

3. Type C letters - reflective sheeting

a. Photometric
b. Color
c. Adhesive
d. Durability
e. Fabrication

C. Paints

D. Hardware

II. Fabrication of Signs

A. Aluminum Signs

1. Porcelain-enamel background
2. Reflectorized background

B. Plywood Signs

1. Baked enamel background
2. Paint background

C. Letters, Symbols and Accessories, Legend and Border

1. Reflectorized, cut-out, and removable
2. Screen processed
3. Permanently adhered, reflectorized

II. NOTES ON TEXAS SIGN SHOPS AND FIELD OBSERVATIONS ON SIGNS

A. Purpose

It was desired to observe techniques and practices of sign shops in different areas in Texas. The purpose was to become familiar with shop problems and materials problems, particularly from the standpoint of materials and materials specifications.

Only one shop in Texas is completely equipped to fabricate signs from retroreflective sheeting. This is the shop in Austin, and because this shop and its practice have been covered in reports by the Texas Highway Department, it was reviewed in an appropriate section in Part I of this report. The other shops visited manufacture signs with beads-on-paint and some others. In addition to the manufacture of signs, problems of maintenance and of sign durability were observed.

B. Sign Shops and Geographical Areas Visited

1. Texas Highway Department, Austin Headquarters
   Central Shops and Laboratories
   Central Texas area

2. THD District 15, San Antonio
   South Central Texas area

3. THD District 8, Abilene
   North Central Texas area

4. THD District 6, Odessa
   West Central Texas area

5. THD District 12, Houston
   Southeast Texas Coastal area

6. THD District 4, Amarillo
   Northwest Texas

C. Types of Signs Manufactured

Beads on Paint Facings. Commonly applied on plywood and on steel; occasionally on aluminum. This type of sign is manufactured in all of the sign shops in Texas.

Reflectorized Sheeting. All red stop signs are made with reflectorized sheeting. The usual backing is steel. Some signs other than stop signs also are made with reflectorized sheeting.

Interstate Signs. These are of two main types, reflectorized sheeting on plywood or metal and porcelain enameled aluminun. These signs usually are manufactured by a contractor.

Delineators. These usually are plastic reflecting buttons and are assembled and mounted in sign shops.

Message Units. These may be made from prefabricated letters in which are mounted reflecting buttons. Retroreflecting sheeting also is cut to shape the required letters, numbers or symbols and mounted on the signs by means of pressure sensitive adhesive backing.

Nonreflecting paint on wood or metal.

D. Fabrication Procedures

Beads on Paint. Metal sign blanks are purchased from the warehouse in Austin, and plywood sign blanks are cut to size at the individual sign shops. In both types, the base coat of paint is applied by automatic paint spraying machine and air-dried at least 24 hours. Paint is applied to one side (face) only by an automatic sprayer to a specified depth, and glass beads are spread on the wet paint surface immediately, using a semiautomatic hopper-fed spreader. Excess beads are shaken off and sign is stacked for air-drying 24 hours or until stock sign is required. Lettering, symbols, borders, etc., are applied by silk-screen process or by hand painting, if necessary for special signs.

Reflectorized Sheeting. Few district shops are equipped to handle sheeting. It is presently applied to sign backings at the State Highway Sign Shop in Austin, which was discussed in Part I.

E. Maintenance Procedures

Each district is responsible for the maintenance of all signing in its district. Noninterstate signing maintenance is the responsibility of the county maintenance superintendent for state highways and county maintenance units for county road signing. Destroyed signs are immediately replaced. At six-month intervals the sign shop foreman tours the district for the purpose of checking or evaluating signing for evidence of deterioration such as decrease in reflectivity, fading and dirtiness. On the basis of his judgement, signs may be pronounced as still useful, in need of cleaning, patching, etc., or is to be replaced.

In a number of district shops each sign may be dated when finished and dated again when erected on the highway. This is useful for the purpose of determining the use-life. The red reflectorized stop signs are dated by all of the districts because of the 5-year guarantee on the sheeting.

Cleaning is generally not done on a routine basis but as needed. The beads-on-paint signs are cleaned with water and sometimes water and detergent. The reflectorized sheeting is not cleaned. The red stop signs are routinely cleaned and oversprayed (clearcoat) as recommended by the sheeting manufacturer.

F. Comments Regarding Use-Life

Life of Sign Versus Cost of Materials. The average life of a highway sign has been unofficially assumed to be four to five years. Failures are due to normal weathering and many other factors such as damage by vehicles, severe or unusual exposure environment, vandalism, and others. The use of expensive materials for sign fabrication has been questioned if the purpose of the higher cost is to provide longer projected use life. There is not an adequate basis for making firm judgement on this at present. Greater emphasis might be placed on short-term durability or use-life, such as cleanability, ease of fabrication, repairable facings, and nonstaining facings.

Storage of Signs and Signing Materials. It has been indicated that signs which are erected after having been in storage for extended periods of time deteriorate more rapidly on exposure than do freshly fabricated ones.

Cleanability. The cleanability of sign facings has a definite influence on the use-life of a sign. Some materials cannot be effectively cleaned by the usual soap and water or cleaning fluid methods. Thus, some signs must be replaced, not because they are "worn out," but because the sign facing could not be kept cleaned of surface dirt.

Recording of Signs for Greater Use-Life. Dating of signs as they are erected and recording the locations would provide a means for determining where a better quality/higher priced material might be used to advantage. In an area of high replacement frequency for signing, an inexpensive material would be justified.

G. General Conclusions

Reasons for Removal of Signs from Service. A sign under normal exposure conditions and properly fabricated should not require replacement for 8 to 10 years or longer. However, many factors influence the useful life of a sign other than normal environmental exposure, such as, improper fabrication techniques causing early failure, destruction or damage of signs by vehicles, poor or inferior quality materials causing premature sign replacement. Also, lack of, or improper, maintenance procedures and damage caused by the elements such as wind, rain, hail, blowing sand may shorten the expected life of a sign. Vandalism is one of the major causes of premature sign replacement. Many signs are deliberately destroyed or damaged by collision, thrown objects, staining fluids and other means. There is evidently little that can be done to prevent vandalism except to make the signing less susceptible to this kind of degradation.

Durability of Signing Materials. Directly related to durability factors are the time involved in maintenance and costs of replacement. A number of factors with which the durability of material may be directly related to the use-life of signs are (1) cleanability, (2) color fading, (3) reduction of brightness, (4) buckling and wrinkling, (5) surface defects, and (6) bond failure.

The principal mechanisms of degradation of reflective sheeting*, involve heat, chemical reaction and photochemical reaction. One effect of heat is to accelerate chemical reactions and, in effect, eventually lead to "overcurring". The rate of reaction generally doubles for each increase of 10°F in temperature. Another effect of heat is to cause decomposition by exceeding the stability temperature. Still another effect is to cause degradation of pigments by slow oxidation. Degradation of sheeting may also be based on reactions of the resins with their environment. The most important is reaction with water. Degradation may proceed because of activity of plasticizers. In some resins, water is a plasticizer. Secondary reactions of some importance are with atmospheric materials such as O_2, ozone, CO_2, sulfur or NO_2. Some chemical reactions, called photochemical reactions, may be accelerated due to the effects of specific frequencies of radiation. Breakdown may be at a specific wavelength and, consequently, laboratory tests may not be valid.

Testing can be conducted in three phases to establish performance potential. These are: (1) Weatherometer** tests, (2) exposure racks, and (3) field testing.

*Much of this information was obtained from Minnesota Mining and Manufacturing Company.

**Atlas Electric Devices Company, Chicago, Illinois

The Weatherometer is the least useful. However, when applied to specific needs, it is of value. Certain resins react more to specific wave lengths than others. A thorough knowledge of the resins involved makes it possible to prepare experimental compositions that enable rapid estimates to be made. The Weatherometer is useful as a check for particular effects of moisture, temperature and wavelength cycles. It is used in the development of new resins and can indicate bad formulations. The radiation emitted by conventional models does not closely resemble sunlight. New models using a xenon tube, furnishs a spectrum similar to sunlight, but of low intensity.

Exposure racks are used to furnish meaningful data. A summary of the program as conducted by the Minnesota Mining and Manufacturing Company follows:

> Most panels are 3" X 10". Each exposure rack has 11,000 samples. Exposure racks are located at Minneapolis; Southern Florida; Sugarland, Texas; and Phoenix, Arizona. In Florida the samples face south to get maximum exposure. There, the samples are tilted at 45° to be more nearly normal to the sun's rays.
>
> The exposure in Florida is said to be the most severe in the world. People from all over the world use exposure racks in Southern Florida.
>
> The racks at Sugarland, Texas are mounted vertically. In Phoenix, the system is set to get maximum radiation in a dry atmosphere; the panels are mounted so as to face the sun all day and to rotate with it. The panels also automatically rotate so as to stay normal to the sun's rays at all times. In addition, ten (10) mirrors are focused on each panel.
>
> In addition, some tests are mounted in Chicago, Detroit and Cleveland; and in the Pacific Northwest for maximum cloud cover.
>
> The most severe degradation occurs in a Southern Florida station; the least severe in Phoenix. The time of exposure in Florida X 2.5 is about right for failure in Sugarland, Texas.
>
> It has been demonstrated definitely that the most severe exposure is a combination of moisture, sunlight, and heat. For the four exposure sites, the most severe is Southern Florida, next is Sugarland, Texas, and last is the racks in Phoenix. The exposure racks in Florida, mounted at 45°, may result in failure in two (2) years, although evidence of failure appears during the first year.

The first evidence of failure is the appearance of fine surface cracks in the flat-top coating. If this is given a thin surface coating at that stage, the service life is extended. It has been demonstrated that the combination of sunlight, moisture, and heat does rapidly hasten deterioration. Consequently, the sign blank material is of importance. For example, the worst apparently would be porous wood. The final and most reliable test is to install actual signs on highways and visit once per year to get data.

No information was found on the effects of exposure on mechanical properties of sheeting and of mounted signs. It is expected that exposure might influence mechanical properties as tested in tension and in flexure. Other factors such as hardness, color microstructure also may be vulnerable to weathering.

III. MANUFACTURERS OF SIGN MATERIALS

A. Survey of Sign Materials Manufacturers

Questionnaires concerning highway signing materials were sent to a number of manufacturers.

Of the twelve companies returning the questionnaire, eight were sign fabricators, three were manufacturers of facing materials for highway signs, and one was a manufacturer of plastic reflecting buttons.

B. Commercial Sign Facing Materials

Facing materials are available in both reflective and nonreflective sheeting, beads, paints, enamels, buttons and other preparations. Bonding methods are by use of pressure, heat or various adhesives. The following indicates this variety of materials available:

(1) Reflective and nonreflective sheeting with adhesive backing for pressure bonding or for thermoplastic bonding.

(2) Reflective and nonreflective sheeting in the form of decalcomania or transfer strip, either wet or dry.

(3) Retroreflective surfaced signs and panels prepared by the manufacturer.

(4) Retroreflective paint used for delineators and the like.

(5) Beaded panels - beads on paint panels and signs.

(6) Prismatic reflectorized sheeting.

(7) Reflector buttons.

(8) Porcelain enamel on aluminum or steel.

(9) Baked organic enamel on various backings.

(10) Letters and message units cut from reflective sheeting; prefabricated units comprised of reflective buttons, pre-mounted in baked organic enamelled aluminum.

(11) Color fluorescent sheeting.

(12) Reflectorized and nonreflectorized paints.

C. Materials Available for Sign Backings

Among the materials available for sign backings are:

(1) Aluminum

(2) Steel, aluminum-clad

(3) Steel, coated and uncoated

(4) Wood, plywood in various grades.

D. Manufacturers of Materials for Facings, Backings and Beads

The following listing is probably not complete but lists those companies from which we have obtained definite information or product lieterature indicating that they are a sign or sign materials manufacturer. Other companies which were contacted and indicated that they did not manufacture signing materials but were sign fabricators are not included in this list.

1. American Decal and Manufacturing Company
4100 West Fullerton Avenue
Chicago, Illinois 60639

Reflective sheeting with precoated adhesive backing, pressure sensitive and heat applied.

2. Cataphote Corporation
2503 Albion
Toledo, Ohio

Beaded panels, factory applied.

3. E. I. DuPont de Nemours
Film Division, Chestnut Run Laboratory
Wilmington, Delaware

Nonreflective sheeting, special adhesive bonded.

4. Fasson Products (Avery Products Corporation)
250 Chester Street
Painesville, Ohio

Pressure sensitive paper, plastic and foil sheeting, reflective and nonreflective.

5. Flex-O-Lite Manufacturing Corporation
8301 Flex-O-Lite Drive
St. Louis, Missouri

Reflecting spheres (glass beads)

6. Grote Manufacturing Company
Box 766
Madison, Indiana

Plastic reflector buttons

7. Minnesota Mining and Manufacturing Company
2501 Hudson Road
St. Paul, Minnesota

Reflective sheeting of all types

8. Mirawal Company
Port Carbon, Pennsylvania

Porcelain enamel on steel.

9. Pfaff and Kendall
84 Foundry Street
Newark, New Jersey

Porcelain enamel on aluminum.

10. Prefinish Metals, Inc.
2111 E. Pratt Blvd.
Elk Grove Village, Illinois

Special sign backings and sheeting application.

11. Prismo Safety Corporation
Huntingdon, Pennsylvania

Reflective, factory - applied beads in binder.

12. Rowland Products, Inc.
Kensington, Connecticut

Multilensed sheeting, acrylic reflectors.

13. Rupert Manufacturing Company, Inc.
703 South 10th Street
Blue Springs, Missouri

Reflecting highway sign and delineator buttons, acrylic.

14. Elastic Stop Nut Corporation of America
1030 Newark Avenue
Elizabeth, New Jersey

Acrylic reflecting buttons.

15. Topflight Corporation
200 East Ninth Avenue
York, Pennsylvania

Fluorescent and reflective sheeting, pressure sensitive.

16. United States Steel Corporation
Five Gateway Center
Pittsburgh, Pennsylvania

Steel sign backing, coated and uncoated.

APPENDIX I

A PARTIAL LIST OF TEXAS HIGHWAY DEPARTMENT SPECIFICATIONS RELATING TO HIGHWAY SIGNING

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A PARTIAL LIST OF TEXAS HIGHWAY DEPARTMENT SPECIFICATIONS RELATING TO HIGHWAY SIGNING

A. Sign Supports

1. Texas Highway Department Item 7250 Overhead Traffic Sign Supports made from aluminum for interstate routes.

2. Texas Highway Department Item 7270 Overhead Traffic Sign Supports made from steel for interstate routes.

3. Texas Highway Department Item 7220 Roadside Traffic Sign Mounts Types A, B, C, and D made from galvanized pipe for Texas state routes.

4. Texas Highway Department Item 7240 Roadside Traffic Sign Mounts Types E, F, G, H, and Types 1 through 16 made from steel I-beam and wide flange beam for Texas state routes.

5. Texas Highway Department Item 732 Delineator and Milepost marker posts.

6. Texas Highway Department Item 741 Foundations for Traffic Signs.

B. Materials for Highway Signing

Aluminum Signs

One-piece sheet aluminum with one face side reflectorized - "Texas Highway Department Item 7020 Aluminum Signs Type A" and "Texas Highway Department Special Provision to Special Specification Item 7020 Aluminum Signs Type A."

Extruded Aluminum Panels - "Texas Highway Department Special Specification Item 7041 Aluminum Signs Type B" and "Texas Highway Department Special Provision to Special Specification Item 7041 Aluminum Signs Type B."

Aluminum Honeycomb Panels with one face side porcelainized - "Texas Highway Department Special Specification Item 7062 Aluminum Signs Type C" and "Texas Highway Department Special Provision to Special Specification Item 7062 Aluminum Signs Type C."

Multipiece Sheet Aluminum signs which have a green porcelain enamel on the face side - "Texas Highway Department Special Specification Item 7031 Aluminum Signs Type D" and "Texas Highway Department Special Provision to Special Specification Item 7031 Aluminum Signs Type D."

Sheet Aluminum Honeycomb Panels which have a reflectorized background on the face side - "Texas Highway Department Special Specification Item 7051 Aluminum Signs Type E" and "Texas Highway Department Special Provision to Special Specification Item 7051 Aluminum Signs Type E."

One-piece Sheet Aluminum signs which have white porcelain enamel on the face side - "Texas Highway Department Special Specification Item 7071 Aluminum Signs Type F."

Steel Signs

One-piece Sheet Steel signs which have the face side reflectorized - "Texas Highway Department Item 7010 Steel Signs Type A" and "Texas Highway Department Special Provision to Special Specification Item 7010 Steel Signs Type A."

Plywood Signs

High Density Plastic-Faced Plywood sign blanks having sign faces reflectorized with Flat Surface or Exposed Lens Flexible Reflective Sheeting - "Texas Highway Department Special Specification Item 7001 Plywood Signs Type A and Type B" and "Texas Highway Department Special Provision to Item 7001 Plywood Signs Type A and Type B." Specifications for the High Density Plastic-Faced Plywood are listed in "Texas Highway Department Special Specification Item 7200 Plastic-Faced Plywood for Traffic Signs."

Medium Density Plastic-Faced Plywood sign blanks having sign faces reflectorized with Paint and Beads - "Texas Highway Department Special Specification Item 7001 Plywood Signs Type A and Type B" and "Texas Highway Department Special Provision to Item 7001 Plywood Signs Type A and Type B."

Messages

Removable Reflectorized Messages - "Texas Highway Department Item 7160 Removable Reflectorized Cutout Letters, Numerals, Arrows, Symbols, Corner Radii for Sign Borders, Borders, and Reflectorized Outlines for U. S. and State Route Markers."

Delineators

Acrylic Plastic Prismatic Reflector Unit Delineators - "Texas Highway Department Special Specification Item 7301 Delineators" and "Texas Highway Department Special Provision to Special Specification Item 7301 Delineators."

C. Retroreflective Sign Surfacings

Delineators

Texas Highway Department Special Specification Item 7301. Texas Highway Department Special Provision to Special Specification Item 7301.

Cutout Letters

Removable Reflectorized Cutout Letters, Numerals, Arrows, Symbols, Corner Radii for Sign Borders, Borders and Reflectorized Outlines for U. S. and State Route Markers. Texas Highway Department Item 7160.

Bead Reflectorization, Green Background

Bead Reflectorization for Signs Having a Green Background. Texas Highway Department Item 7140.

Bead Reflectorization, Yellow and White Backgrounds

Bead Reflectorization for Signs Having a White or Yellow Background. Texas Highway Department Item 7120.

Exposed Lens Flexible Sheeting

Exposed Lens Flexible Reflective Sheeting. Texas Highway Department Item 7100.

Flat Surface Flexible Sheeting

Flat Surface Flexible Reflective Sheeting. Texas Highway Department Item 7080.

Special Provision to Special Specification, Flat Surface Flexible Reflective Sheeting. Texas Highway Department Item 7080.

Paint

Texas Highway Department Paint Specifications.

Texas Highway Department Special Provision No. 1 to Paint Specification D-9-1, 4-61.

Texas Highway Department Special Provision No. 2 to Paint Specification D-9-1, 4-61.

Texas Highway Department Special Provision No. 3 to Paint Specification D-9-1, 4-61.

Fabrication, Plywood Signs, Types A and B

Texas Highway Department Special Specification Item 7001, Plywood Signs, Types A and B.

(3) Sign face reflectorization
(4) Application of reflective sheeting
(5)(6) Application of bead reflectorization
(7) Sign backs
(8) Sign messages and borders

Fabrication, Steel Signs, Type A

Texas Highway Department, Steel Signs, Type A, Item 7010.

(3) Sign face reflectorization
(4) Application of reflective sheeting
(5) Bead reflectorization
(6) Sign messages and borders

Texas Highway Department Special Provision to Special Specification Item 7010, Steel Signs, Type A, Application of reflective sheeting.

Fabrication, Aluminum Signs, Type A

Texas Highway Department, Aluminum Signs, Type A, Item 7020.

(3) Sign face reflectorization
(4) Application of reflective sheeting
(5) Bead reflectorization
(6) Sign message and border.

Texas Highway Department Special Provision to Special Specification Item 7020, Aluminum Signs, Type A. Application of reflective sheeting.

Fabrication, Aluminum Sign, Type D

Texas Highway Department Special Specification Item 7031, Aluminum Signs, Type D.

(7) Sign messages and borders

Texas Highway Department Special Specification Item 7041, Aluminum Signs, Type B.

(8) Sign messages and borders

Fabrication, Aluminum Signs, Type E

Texas Highway Department Special Specification Item 7051, Aluminum Signs, Type E.

(3) Sign face reflectorization
(4) Application of reflective sheeting
(5) Application of bead reflectorization
(7) Messages and borders

Special Provision to Special Specification Item 7051, Aluminum Signs, Type E. Application of reflective sheeting.

Fabrication of Aluminum Signs, Type C

Special Specification Item 7062, Aluminum Signs, Type C.

(7) Sign messages and borders

D. Porcelain Enameled Aluminum Signs

Aluminum Signs, Type D. (Special Specification Item 7031)

Aluminum Signs, Type B. (Special Specification Item 7401)

(3) Porcelain enamel
(4) Surface preparation

(5) Application of enamel to face of extruded panels
(6) Application of enamel to back side of extruded panels

Aluminum Signs, Type C. (Special Specification Item 7062)

(2) Sheet aluminum honeycomb sign panels
(3) Porcelain enamel
(4) Application of porcelain enamel

Aluminum Signs, Type F. (Special Specification Item 7071)

(2) Sign blanks
(3) Porcelain enamel
(4) Surface preparation
(5) Application of porcelain enamel

APPENDIX II

GENERALLY RECOGNIZED STANDARDS AND TESTS APPLICABLE TO SIGNING MATERIALS

APPENDIX II

GENERALLY RECOGNIZED STANDARDS AND TESTS APPLICABLE TO SIGNING MATERIALS

The subject matter of concern here is that dealing with specifications, standards, and tests for highway facing materials. Each of the 50 states, except Alaska, has specifications for sign facing materials. The complexity of these specifications varies among the 49 states. Copies of these specifications are available and have, in general, been reviewed during this project.

Some widely accepted standards and tests, not authored by individual states, are of interest. These are listed here for reference purposes.

A. <u>Reflective Sheeting</u>

1. <u>Brightness</u>

SAE standard photometric procedure for reflex reflectors

ASTM D-985

2. <u>Gloss - Paints, Plastics, etc.</u>

a. Sixty-degree specular gloss in all ranges except very high or low gloss.

ASTM D523-53T
Federal Test 141:6101
NEMA LP2-213

b. Twenty-degree specular gloss of high gloss surfaces.

ASTM D523-53T
Federal Test 141:6104

c. Gloss and image sharpness of high gloss.

No standarized methods to date.

3. <u>Color - Daylight</u>

a. Forty-five degree - zero degree directional reflectance of opaque diffuse materials.

ASTM E97-55
ASTM D307-44
ASTM D791-61T

b. Any sheeting - retroreflective or diffuse

AASHO Standard interstate colors
ICI Chromaticity chart No. 23

c. Color difference

ASTM D1365-60T

4. Color Fading

a. Fadometer test

ASTM: E240-64T

Federal test TT-P-1416, Method 615-2

5. Durability

Weather resistance

ASTM: E-42-57 Type D
ASTM: D822-60
ASTM: E239-64T
ASTM: E188-63T

6. Rainfall - Wet Performance

MIL-R-13689-A

7. Sheeting Strength

ASTM D828-60
ASTM D987-48T

8. Adhesion

ASTM D903-49

B, Sign Backing

1. Aluminum, Plain Chromate Coating

MIL-C-5541

2. Baked Enamel on Aluminum

Federal Test TT-E-489

C. Reflector Buttons

1. Acceptance Test

Federal Specification L-M-500a, Type 1, Class 3

2. Color Fastness

ASTM D620-49

D. Reflectance

1. Goniophotometry of Reflecting Materials

ASTM: E-167-63
ASTM: E-179-61T

APPENDIX III

STANDARDS, SPECIFICATIONS AND TESTS FOR PORCELAIN ENAMEL METAL APPLICABLE TO HIGHWAY SIGNING

APPENDIX III

STANDARDS, SPECIFICATIONS AND TESTS FOR PORCELAIN ENAMEL METAL APPLICABLE TO HIGHWAY SIGNING

Reflectance Test for White Enamels

Porcelain Enamel Institute, Quality Development Committee, "Reflectance Test for Opaque White Enamels - Standard Test," Porcelain Enamel Inst. Bull., T-13, 7 pp (1952).

Standard Test for Adherence

Porcelain Enamel Institute Quality Development Committee, "Test for Adherence of Porcelain Enamel to Sheet Metal - Standard Test," Porcelain Enamel Inst. Bull., T-17, 15 pp (1953).

Abrasion Test Tentative Standard

Porcelain Enamel Institutes, Quality Development Committee, "Test for Resistance of Porcelain Enamels to Abrasion - Tentative Standard," Porcelain Enamel Inst. Bull., T-2, 12 pp (1955).

Recommended Test Methods for Evaluation and Control of Porcelain Enamel on Aluminum - Tentative Standard

Acid Resistance - The Porcelain Enamel Institute Bulletin T-7, "Test for Acid Resistance of Porcelain Enamels, Part I - Flatware" (A Standard of the Porcelain Enamel Institute) and ASTM Standard C282-53, "Standard Methods of Tests for Acid Resistance of Porcelain Enamels," (ASTM Standards 1955, Part 3, Page 829) are recommended.

Abrasion Resistance - Section IV of the Porcelain Enamel Institute Bulletin T-2, "Test for Resistance of Porcelain Enamels to Abrasion," (A Tentative Standard of the Porcelain Enamel Institute) is recommended. This section is concerned with subsurface abrasion testing. It is suggested that an additional Volume Index (standard index divided by density of the porcelain enamel) be reported to indicate a compensation for wide variations in density.

Chemical Resistance -

a. Acid Solubility

The boiling acid resistance tests as found in "Commercial Standard CS100-47, Porcelain Enameled Steel Utensils, 3rd Edition, December 1947," and ASTM C283-54 "Standard Method of Test for Resistance of Porcelain Enameled Utensils to Boiling Acid," (ASTM Standards 1955, Part 3, Page 843) are recommended. Maximum weight loss standards are not to be applied to porcelain enamel on aluminum. Weight loss in grams per square inch is used to indicate resistance to solubility by acid.

b. Alkali Solubility

A test modeled after the boiling acid resistance test above, and using the same apparatus, time, temperature, etc., as for acid solubility, with 5% by weight solution of tetra sodium pyrophosphate (anhydrous) substituted for the citric acid solution is recommended. Weight loss in grams per square inch is used to indicate resistance to solubility by alkalies.

(Note: The Quality Development Committee of the Porcelain Enamel Institute is at this time evaluating a new apparatus and test method on alkali resistance. This subcommittee will consider this test apparatus and method to replace the above method when the present evaluation is complete.)

Color Measurements - Standard samples in nonfading material and visual comparison under at least two light sources (yellow incandescent and blue fluorescent) often serve the requirements. Standard color booths with two light sources may be purchased. Readings from a Tristimulus Reflectometer such as a color difference meter will serve to give a mathematical notation for control purposes. Visual matching must be used in conjunction with the meter when types of material and coloring chemicals are different.

Gloss Measurements - The Porcelain Enamel Institute Bulletin T-18, "Gloss Test for Porcelain Enamels."

Spall Test to Determine Retention of Adherence - The spall test described below is recommended as an accelerated test for retention of adherence in service. Improper alloys, treatment prior to porcelain enameling, cleaning and processing may result in an inferior quality due to spalling. Freedom from spalling to bright aluminum after testing indicates good quality.

To test for spalling, the specimen is immersed at room temperature in a 5% by weight freshly prepared solution of C. P. ammonium chloride in distilled water.

Whenever possible, testing of a deformed sample is recommended for standard procedure. Permanent deformation of the sample prior to immersion is desirable to accelerate the test and expose greater area to danger of spalling. Edges should be filed to expose the aluminum enamel interface on all samples. Edge spalling predominates on samples which are not deformed.

Exposure time should be 96 hours for normal samples, and 24 hours for deformed samples. Use at least 25 cc of solution per square inch of sample.

Method of Deforming for Spall Test

a. Samples on 0.064" thickness aluminum with maximum coating of 0.004" thickness on one side only are deformed by bending 180° over a 3/4" diameter mandrel with the coating on the external surface. Edges of sample are filed back to expose enamel-metal interface before deforming.

b. Larger diameter mandrels would appear to be practical for thicker aluminum or thicker coatings.

Torsion Resistance - This is a test for comparative qualities of the porcelain enamel. Comparisons must be made using the same alloy for angles, since the physical properties of the alloy influence results.

The Porcelain Enamel Institute Bulletin T-5, "Torsion Test for Porcelain Enameled Iron and Steel." This test gives a qualitative evaluation of the tendency to fracture due to distortion.

Results are obtained with aluminum 0.051" and over in thickness and coatings 0.005" and over in thickness.

Angles may be formed in the standard sheet iron die by careful manipulation and regulation of pressure.

Thickness Measurements - Micrometer readings prior to application of the coating compared to micrometer readings after the coating serve to indicate thickness. When original thickness of the aluminum is unknown, or when coating is applied on each side, this method is not practical.

Coating thickness can be measured by eddy-current devices in which the frequency varies with the distance the coil (probe) is displaced from the underlying metal. Instruments of this type compare this frequency with a reference frequency, the coating thickness being a function of the capacitance required to equate the two frequencies. Instruments based on this principle are produced by the American Instrument Company, 8030 Georgia Avenue, Silver Spring, Maryland, and by the Boonton Radio Company, Boonton, New Jersey.

Weather Test - There is no sure substitute for actual weather exposure tests. Samples of porcelain enamel on aluminum are being included in the new Porcelain Enamel Institute - National Bureau of Standards weathering test program. Specimens are being placed on exposure at six selected sites throughout the country.

Comparison of chemical resistance of materials of proven weather resistant characteristics with the chemical resistance of new materials is the best known method for rapid evaluation of porcelain enamel coatings.

a. Color Retention

Certain types of porcelain enamels are subject to color fading in outdoor exposure. These are predominantly shades of red and yellow. Freedom from discoloration when the surface is exposed to a few drops of 70% nitric acid for 15 seconds at room temperature is suggested as a test for fading.

Dirt Retention and Cleanability - Porcelain enamels are not stained by materials used in conventional tests for organic finishes. A test for staining and cleanability will be found in "Military Specification MIL-A-16994B (Navy) May 9, 1955, Aluminum Alloy Sheets, Flat, Porcelain Enamel Coated."

Testing of Adherence by Deformation - Attention is called to the Porcelain Enamel Institute Bulletin T-17, "Test for Adherence of Porcelain Enamel to Sheet Metal." While the presently known porcelain enamels for aluminum do not seem to exhibit variations in adherence by this type of test, it appears that new formulations may be developed which will require some evaluation of adherence by deformation.

Strength of Porcelain Enameled Aluminum - A subcommittee has work in progress wherein the physical properties of the aluminum, after coating with porcelain enamel, are determined.

Scratch and Gouge Resistance - It appears desirable to consider some form of scratch or gouge test to determine the quality of porcelain enamel on aluminum. Foremost among these would appear to be the consideration of some form of gouge test, which would show the difference in quality obtained when the porcelain enamel was applied over different types of alloy.

Bulletins Available from the Porcelain Enamel Institute - Bulletins of the Porcelain Enamel Institute referred to in this work are listed below. All of these publications may be purchased from the Porcelain Enamel Institute, Inc., 1145 Nineteenth Street, N. W., Washington 6, D. C.

	Title	Price
Bulletin T-7	Test for Acid Resistance of Porcelain Enamels, Part I - Flatware	$0.25
Bulletin T-2	Test for Resistance of Porcelain Enamels to Abrasion	.50
Bulletin T-18	Gloss Test for Porcelain Enamels	.25
Bulletin T-5	Torsion Test for Laboratory Specimens of Porcelain Enameled Sheet Iron and Steel	.25

Other Publications - Other publications referred to may be obtained as indicated:

ASTM C282-53 Standard Methods of Test for Acid Resistance of Porcelain Enamels, ASTM Standards 1955, Part 3, page 829. (Available from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.)

ASTM C283-54 Standard Method of Test for Resistance of Porcelain Enameled Utensils to Boiling Acid, ASTM Standards, 1955, Part 3, Page 843. (Available from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.)

Commercial Standard CS100-47, Porcelain Enameled Steel Utensils, December 7, 1947. (For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.)

Military Specifications, Aluminum Alloy Sheets, Flat, Porcelain Enamel Coated, MIL-A-16994B (Navy) May 9, 1955. (For distribution by Commanding Officer, Naval Supply Depot, Scotia 2, N. Y.)

Gloss Test - Tentative Standard

Porcelain Enamel Institute, Quality Development Committee "Gloss Test for Porcelain Enamels - Tentative Standard," Porcelain Enamel Inst. Bull., T-18, 7 pp (1953).

Processing Methods - Tentative Standard, Porcelain Enamel Institute, Aluminum Division, Processing Methods Subcommittee, "Recommended Processing Methods for Porcelain Enamel on Aluminum Alloys - Tentative Standard," Porcelain Enamel Inst. Bull., AL-2a, 29 pp (1956).

Compilation of Standards and Specifications on Porcelain Enamel Coatings MIL-E-6802 and MIL-P-16961

Standards and specifications prepared by Government agencies and National organizations were compiled by Kaedonovsky(146).

Revised Specifications for Porcelain Enameled Aluminum for Weather Exposure

The new specifications are designated PEI: ALS-105(64) and replace a specification issued in 1958.

ASTM Standards

ASTM, "Terms Relating to Porcelain Enamel," ASTM Std., 1961, Part V, pp 635-42. ASTM Designation C286-61 revised.

ASTM, "Torsion Resistance of Laboratory Specimens of Porcelain Enameled Iron and Steel," ASTM Std., 1961, Part V, pp 621-28.