HIGHWAY SIGNING RESEARCH

PHASE II. CHARACTERIZATION OF SIGN-FACING MATERIALS

THD No. 5-1-65-86
SwRI Project No. 07-1650-02
FINAL REPORT

by

J. E. Funnell
D. K. Curtice

Prepared under Contract HPR-1(5)

for

Texas Highway Department
State Highway Building
Austin, Texas 78701

and

U. S. Department of Commerce
Bureau of Public Roads
Washington, D. C.

August 5, 1966

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SAN ANTONIO HOUSTON

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SUMMARY

A program was conducted to develop, through laboratory and related field studies, sufficient information on which to judge the adequacy of current performance specifications for sign-facing materials. Employing materials in common use in highway signing, studies were carried out to characterize them with respect to qualities identifiable with optimum sign performance and serviceability. Portions of the work were concerned with defining objective criteria for specifying those qualities and examining test procedures and requirements to evaluate the materials with respect to the criteria.

The general technical areas of work were: 1) durability, including mechanisms of deterioration; 2) photometric properties; 3) cleanability; 4) methods and ease of fabrication; 5) physical and mechanical properties; 6) selection and development of photometric instruments; and 7) others -- including sign monitoring, review of Texas Highway Department data on signing materials, and accelerated tests.

Several generic classes of reflective facing materials were studied, with emphasis being placed on commercially available sheeting of the flat-surface and exposed-lens types and on the beads-on-paint non-sheeting type. Exhibiting different characteristics as to performance and capabilities, these are more or less complex, composite structures, built of organic and inorganic base materials. Their durability is a function of the rate and severity of deterioration of constituent materials by a variety of chemical and physical mechanisms. The organics, which comprise a major portion of the structures, are the least durable. Sign-backing materials were also examined, primarily on the basis that they are "wedded" to and can affect the performance of facings.

Findings of the program have indicated some inadequacies in current sign performance specifications, particularly as to definition of service requirements. The dry and wet reflectance of reflective signing materials should receive primary consideration as a basis for rating the performance and serviceability of signs, both as to brightness or brilliance and contrast between lettering and background. Specifications on cleanability, abrasion resistance, and other features pertaining to sign performance, serviceability, and maintenance may be related to the photometric properties of facing materials and the acceptable limits within which they may influence them. In this program, most of the changes occurring in materials from various treatments and exposures could be correlated with performance capability through measurement of photometric properties.

While colors play an important role in signs, there does not appear to be a particular need to fix definite values for them in performance specifications. For both reflectance and color, there is a need for the development and use of

calibration methods which will make it possible to compare data from one facility to another, particularly where retroreflective color measurements are being made.

Test methods and equipment examined in the studies were not always found to be adequate for evaluation of materials with respect to objective criteria identifiable with optimum sign performance and serviceability. In those cases where inadequacies were evident, attempts were made to fulfill needs by developing methods and equipment or modifying those already known.

It has been recognized that the scope of this program was rather broad for a one-year contract period. However, the work accomplished and results obtained are felt to have contributed much toward a better understanding of the character, behavior, and performance of sign-facing materials as well as the problems associated with their use. Results of the overall investigation have pointed to areas requiring additional study, particularly with regard to factors influencing durability and use-life expectancy of signing materials, new and/or improved instrumentation and procedures for photometric property determinations in laboratory and field, accelerated tests for evaluation of durability, effects of different service conditions (nationwide) on durability and use-life of various signing materials, and others.

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I. INTRODUCTION

The purpose of this investigation has been to develop, through laboratory and related field studies, sufficient information to permit appraisal of the adequacy of current performance specifications for sign-facing materials. In order to accomplish this, the characteristics of available commercial materials of several generic classes were studied to: 1) identify and evaluate the qualities required for optimum sign effectiveness and serviceability, 2) delineate objective criteria for specifying these qualities, and 3) examine test procedures and requirements for the evaluation of signing materials with respect to these criteria. Emphasis was placed on retroreflective materials and their characteristics under various environmental conditions. Other materials and conditions, such as various types of sign backings, adhesives, fabrication methods and requirements, etc., received attention because they often have pronounced influence on sign performance.

Reflective materials for use as facings in highway signing are the most important elements of signs designed to protect and aid night drivers by providing distinct messages that are of warning, regulatory, guiding or informative nature. These signs must perform the same function during daylight hours, as well. Service by both night and day often is under adverse environmental conditions, some of which may radically affect the ability of signing materials to fulfill their purpose satisfactorily.

Previous review of literature related to signing materials revealed little information on their evaluation with respect to types of commercial facings, fabricating characteristics, serviceability, maintenance, useful life-expectancy, deterioration mechanisms, materials standards, reasons for removing signs from service, accelerated durability tests, and so on. While it seems likely that substantial data on these factors exist in the files of state highway departments, certain agencies of the Federal government, and of signing-materials manufacturers, few recognized standards are available and generally accepted. With the development of new signing concepts and new materials, it is apparent that there is a definite need for objective specifications and performance-testing procedures that are both repeatable and reproducible. Standardization of specifications and test requirements is necessary to ensure competitive purchase of materials and their completely satisfactory performance, both as to visual effectiveness and durability.

An effective means of gaining an understanding of how and, to some extent, why sign-facing materials perform and behave in particular fashions is through studies of their makeup, both as to basic materials and structural features. Coupled with exposure to a range of conditions, the studies can provide information on actual or predictable behavior in different environments. From the findings of such work, much may be determined of the relation between materials characteristics, mechanisms of deterioration, and sign performance. Overall results may be used in identifying qualities which are necessary for optimum sign effectiveness and serviceability and can provide a basis for formulating specifications and test methods for evaluating the materials.

At the initiation of this study, the probability was recognized that exposure time attainable within the limited period of the project would not be adequate to provide conclusive and diagnostic results with respect to behavior patterns of materials and mechanisms of their deterioration. However, it was anticipated that some detectable differences would be noted in the behavior of similar specimens exposed to different climatic conditions, as for example, South Florida and San Antonio, Texas. This applies particularly to specimens of materials exposed to normal service conditions, but not to those subjected to accelerated tests.

II. HIGHWAY SIGNING MATERIALS

The materials of principal interest in this work were those commonly used in producing reflective highway sign facings, not including retroreflective buttons. Backing materials, adhesives and other components were also examined in view of their close relation to the serviceability and performance of sign facings and in consideration of how they may influence procedures employed in the fabrication, maintenance and repair of signs. The various types of materials in the above-noted categories that were used and studied in the program are briefly described in this section. Features of construction and characteristics of basic materials are discussed in more detail in the Final Report on Phase I of this program --"A Survey of Materials and Research Needs Relating to Their Use," July 21, 1965.

A. Sign-Facing Materials

1. Generic Classes

a. Flat-Surface, Flexible, Reflective Sheeting

This type of sign-facing material consists of a composite structure composed of a number of functional layers. Typical structures are shown in Figure 1. Often referred to as "over-coated" or "flat-top" because of the smooth, flat surface of the top covering, the sheeting construction may be more or less complex, depending on the desired photometric properties. Figure 2 consists of three photomicrographs showing top views of flat-surface reflective sheeting in which variations in bead arrangement, type and quantity are evident.

Facings of flat-surface, flexible reflective sheeting are applied to sign backings according to instructions and procedures recommended by sheeting manufacturers, and will not be detailed here. Methods and equipment for application and fabrication vary according to the types of adhesives used to bond the sheeting to backings. Since it is important that the facing be free of any features that may distort a sign's message, stress is placed on obtaining a flat-lying, fully bonded relationship between sheeting and backing. To this end, equipment and methods for applying the sheeting through the use of pressure, heat, and vacuum are employed. For assurance that no air bubbles or blisters are formed, the sheeting may be finely perforated.

In the care and maintenance of the sign facings, deviations from manufacturers' recommended procedures can cause damage leading to reduced performance and durability and may even result in effects serious enough to render the facings unserviceable. Repair of signs faced with flat-surface reflective sheeting may involve removal of unserviceable areas and patching, or, in cases of extensive damage, replacement of the entire facing and backing. As in the case of fabrication, care, and maintenance, manufacturers usually recommend procedures to be followed in repair work.

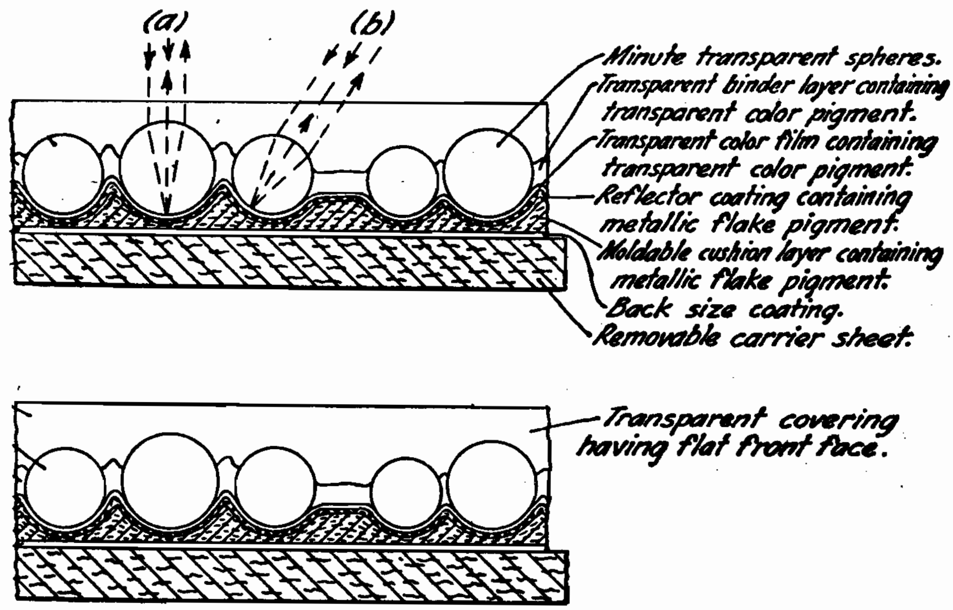


FIGURE 1. CROSS SECTION OF FLAT-SURFACE TYPE OF RETROREFLECTIVE SIGN-FACING MATERIAL

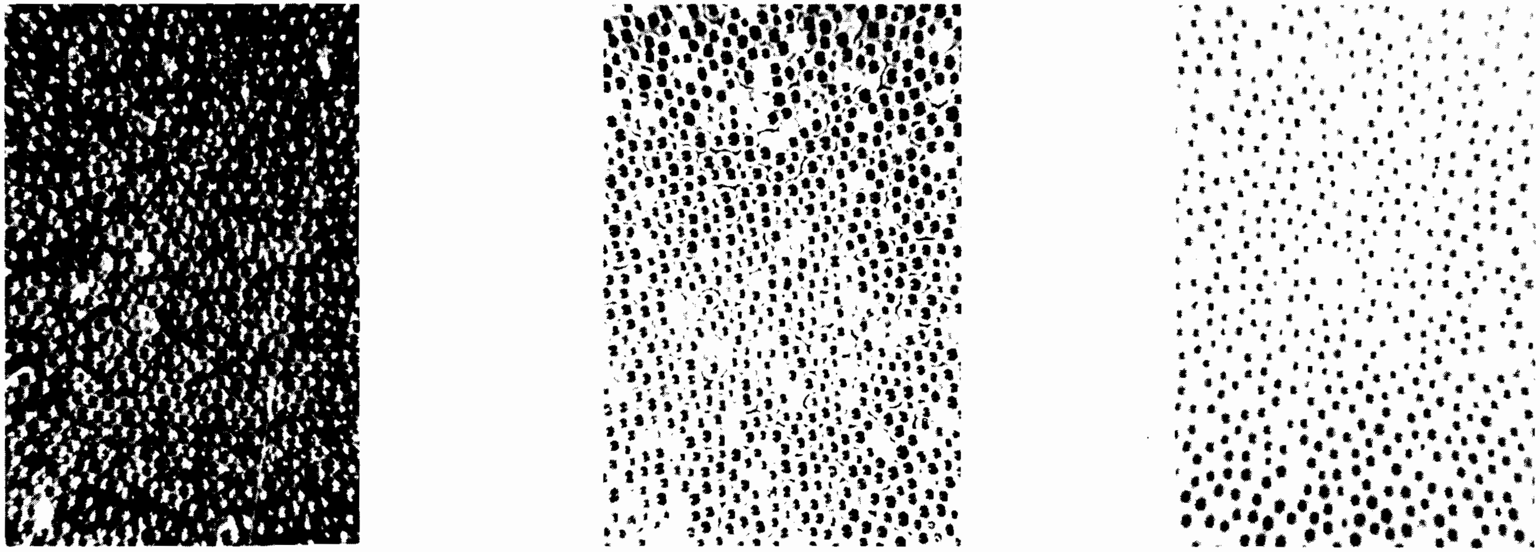


FIGURE 2. PHOTOMICROGRAPHS OF EXAMPLES OF FLAT SURFACE FLEXIBLE SHEETING, GENERIC CLASS 1, REFLECTIVE. Magnification about 30X.

b. Exposed-Lens, Flexible Reflective Sheeting

Reflective sheeting of the exposed-lens type differs from the flat-surface sheeting in that it does not have a smooth, flat covering. Instead, the exposed surface is irregular due to the protrusion of glass beads, which generally have a thin, transparent coating; the glass beads usually are of larger size than those used in flat-surface sheeting. Figure 3 shows cross sections of typical exposed-lens sheeting; Figure 4 shows photomicrographs of top views of sheeting having varied patterns of bead arrangement, type and quantity.

In general, procedures to be followed in the fabrication, care, maintenance and repair of sign facings of exposed-lens, flexible reflective sheeting are the same as for the flat-surface type of sheeting.

c. Beads-on-Paint

This type of sign facing was one of the first to be used on reflective signs. The basic structure of beads-on-paint facings is rather simple, consisting of a base coat of paint which bonds to the backing material, and an overlying paint layer in which reflecting glass beads are embedded but not totally enclosed. Figure 5 shows photomicrographs of beads-on-paint facings having varied glass bead patterns.

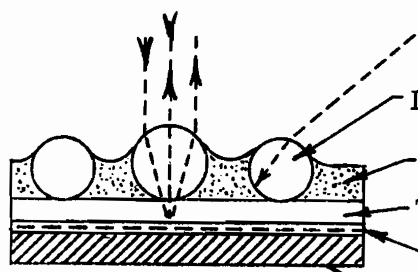
In general, fabrication of beads-on-paint sign facings involves: 1) the spray application of a base coat of paint to the backing, 2) drying, and 3) application of an overlying coat of paint over which glass beads are immediately spread and in which they become embedded. After removal of excess beads, the top coat of paint is allowed to dry. Care is taken to control the thickness of the paint layers, particularly the top coat so as to ensure that the beads are embedded to the desired depth.

Care and maintenance of beads-on-paint sign facings generally do not present particular problems. There have been reports of dirt buildup in spaces between beads but, for the most part, cleaning is accomplished without undue difficulty. Unlike facings of flat-surface and exposed-lens flexible reflective sheeting, beads-on-paint facings usually do not have a clear plastic overlay that is subject to abrasion during cleaning.

Information on procedures for repairing beads-on-paint facings was not obtained in this work. Accordingly, it cannot be stated whether repair of this type of facing is made or is practical.

d. Miscellaneous Sign-Facing Materials

Samples of sign-facing materials of more or less special character were obtained during this investigation. These were not subjected to



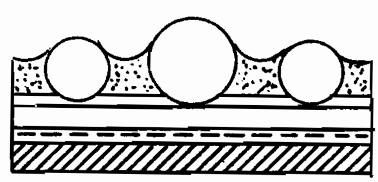


FIGURE 3. CROSS SECTION OF EXPOSED-LENS TYPE OF RETROREFLECTIVE SIGN-FACING MATERIAL

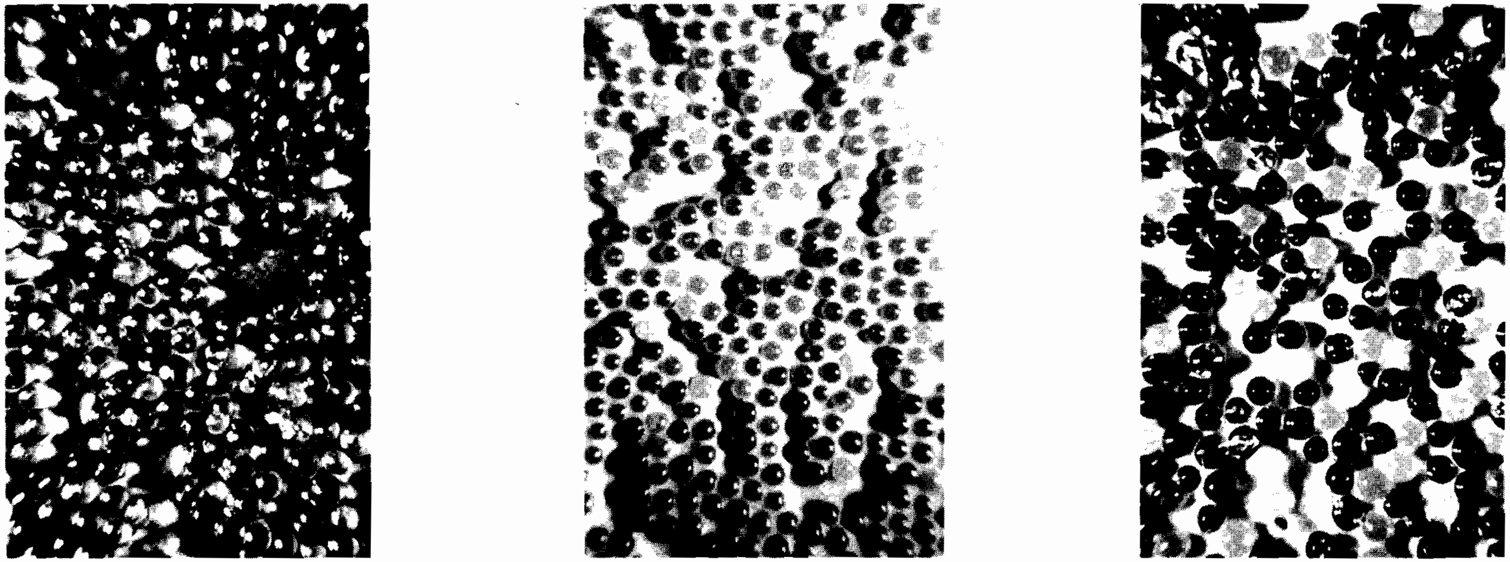


FIGURE 4. PHOTOMICROGRAPHS OF EXAMPLES OF EXPOSED LENS FLEXIBLE SHEETING, GENERIC CLASS 2, REFLECTIVE. Magnification about 30X.

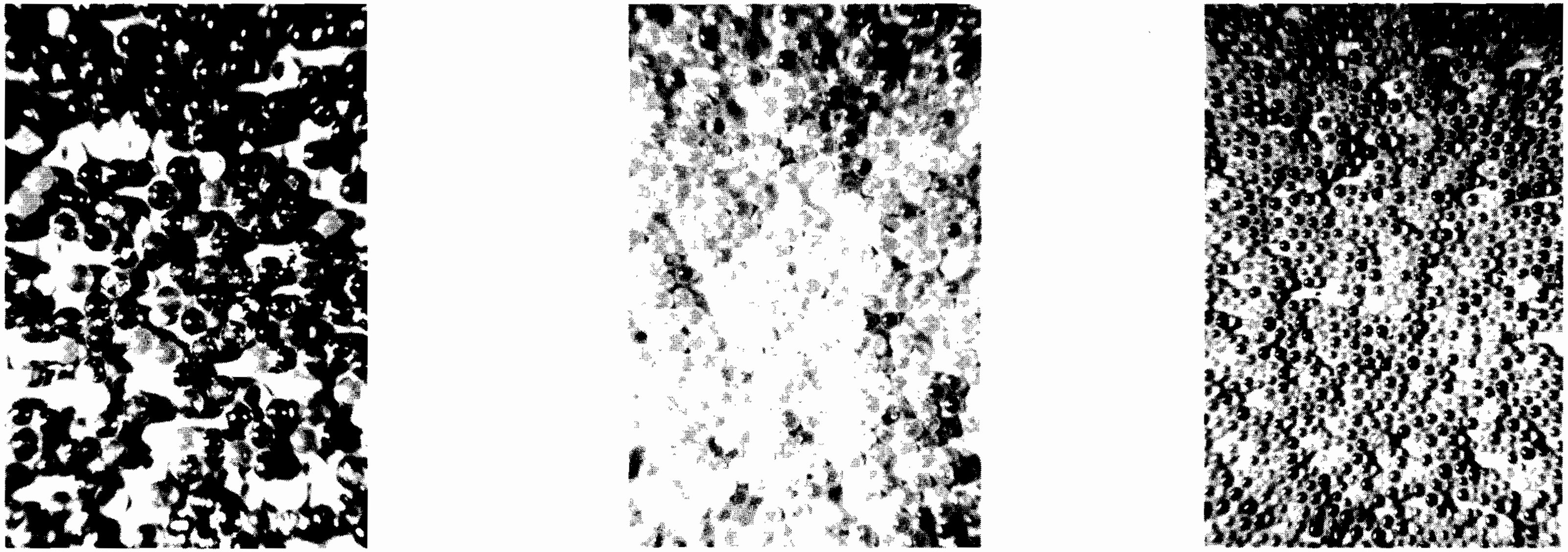


FIGURE 5. PHOTOMICROGRAPHS OF EXAMPLES OF BEADS-ON-PAINT, GENERIC CLASS 3, REFLECTIVE. Magnification about 30X.

detailed study because they currently find little application in highway signing; they were not commercially available; or they were nonreflective. Some studies were made on two types of nonreflective sheeting materials, since they are used in some states as background facings on illuminated overhead signs.

Among the miscellaneous sign-facing materials referred to above were fluorescent sheeting, molded multilens reflective sheeting, nonreflective sheeting, and nonreflective porcelain enamel on aluminum.

B. Backing Materials

Complementary to the faces and message-giving portions of highway signs are the backings which provide smooth, flat surfaces and relatively rigid structures to which sheeting materials and other facing materials are applied. For reflective night signs, flatness of the sign face is particularly important, since irregularities can cause lack of uniformity in brilliance and distortion of the message. The durability and weather resistance of backing materials are also important considerations; the occurrence of warping, bending, corrosion, and other phenomena during service may be as detrimental to sign serviceability as failure of the facing.

The above requirements have led to the use of various backing materials possessing characteristics that generally qualify them for highway-signing application. Cost playing a dominant role, the most commonly used backing materials are plywood, steel, and aluminum. All of these are given appropriate treatments to provide improved surfaces, durability, weather resistance, and other needed features. It appears desirable that the durability and weather-resistance characteristics of backing materials be superior to those of facing materials and that they have longer service life. Otherwise, there is the likelihood that deterioration of the backing will affect the performance of facings. Since backing materials represent a very significant portion of overall sign cost, they should be able to withstand a normal amount of sign repair work and facing replacement without undue degradation of essential qualities.

Wood, steel, and aluminum backing materials of several types were examined in this work. For laboratory fabrication of test panels and specimens, backing materials of plywood, steel, and aluminum meeting applicable Texas Highway Department (THD) specifications were used. These are described as follows:

Plywood - High-Density Plastic-Faced Plywood for use in the fabrication of signs having facings of flat-surface or exposed-lens flexible reflective sheeting, conforming to the THD Special Specification to Item 7003 for Plywood Signs Type A. This backing material, 1/2-inch thick, was cut into panels measuring 3 x 10 and 12 x 12 inches.

Steel - Sheet steel conforming to the requirements of the latest revision of ASTM Specification A-415 as referred to in the

THD Special Specification to Item 7011, Steel Signs Type A. Sign-backing blanks of 12-gauge sheet steel were obtained and cut into panels measuring 3 x 10 and 12 x 12 inches.

Aluminum - Sheet-aluminum sign blanks conforming to the requirements of ASTM Specification B-209 alloy 6061-T6 as referred to in the THD Special Specification to Item 7021, Aluminum Signs Type A, and sheet aluminum as specified for use in various tests. Panels of various thicknesses (0.015- and 0.125-inch) and sizes (2 x 8 to 12 x 12 inches) were cut from sheet-aluminum stock or sign blanks.

In addition to the backing materials used for preparation of samples and specimens, others were examined and/or exposed for determination of weathering characteristics. These included medium-density plastic and/or paper-faced plywood, aluminum-clad steel, plastic-coated aluminum and steel, special steel, porcelain-enameled aluminum, and multipiece-construction aluminum panels of various designs and features.

C. Adhesives

Various types of adhesives are used to bond sign-facing materials to sign blanks and other backings. These bonding agents vary widely with regard to composition, physical properties, method of use, time and means of curing, and other features.

Pressure-sensitive, heat-applied, and solvent-activated adhesives are factory-applied to the backs of reflective sheeting and protected with a paper overlayer; these adhesives thus are integral parts of the sheeting. The principal distinguishing feature between the first three types is the tacky or sticky nature of the pressure-sensitive material. Both of the other two types of adhesives are thin, dry, plastic films of similar appearance; except as noted by the manufacturer, a distinction between the need for heat application or solvent activation generally cannot readily be made.

In this work, the principal use of adhesives was for bonding reflective sheeting to backings of plywood, steel, and aluminum, and for production of beads-on-paint type of facings. The adhesive materials employed included pressure-sensitive, heat-applied, solvent-activated, and paint types; all were commercial products commonly used in highway signing.

The paints used for making beads-on-paint facings were supplied in conventional metal containers and were identified as either exterior or bead-binder materials.

D. Glass Beads

The glass beads used in this work were obtained from the Texas Highway Department, bead manufacturers, and various producers of reflective sheeting. The beads examined were of various sizes; they had refractive indices in the range of 1.90 to 1.94, were mostly spherical and generally clear, and appeared to be of acceptable quality on the basis of such specifications as were available.

III. METHODS, PROCEDURES AND RESULTS

In view of the purposes and objectives of the investigation, the methods and procedures employed in studying signing materials were chosen on the basis of their practicality, adaptability to the needs of the work, and capability of providing meaningful results. A primary consideration was that the overall conduct of the studies be such as to provide guidance and basis for possible future work in the formulation of specifications and test methods for evaluating signing materials.

A. Selection of Materials for Study

The signing materials examined and studied were selected such that the principal generic classes of sign facings would be included; emphasis was placed on those having retroreflective qualities. Most of the materials were representative of those commonly used in highway signing and available from commercial sources, though there were some cases in which experimental materials not in production were examined. With few exceptions, sample lots were obtained free of charge. Throughout the investigation, new and/or improved materials were received from manufacturers. It was not possible to examine all of these as completely as was the case for materials obtained in the early part of the program.

Some of the materials received were not extensively studied because of their special nature or limited relationship to the classes of principal interest. Among these were fluorescent and certain nonreflective materials.

The various types and colors of materials examined are listed in Table I. The sources and identities of the materials are not shown, as this information was not considered pertinent to the study. Instead, a simple numbering code was set up, as shown in the Table. A letter "B" followed by a number indicates the type of backing used with a particular type of facing, as follows:

B1 - High-density plywood.
B2 - Aluminum.
B3 - Steel.
B4 - Aluminum-clad steel.
B5 - Experimental steel.
B6 - "Lightweight" galvanized sheet steel.
B7 - Organic coating on steel.
B8 - Aluminum-coated steel.
B9 - Experimental steel.

Tests performed were, in most cases, according to standard Texas Highway Department, Federal and ASTM test methods. The following list gives

TABLE I. TYPES OF SIGN MATERIALS AND THEIR CODE NUMBERS

Code No.	Type	Color
1	Exposed lens	White
2	Exposed lens	White
3	Flat-surface retroreflective	Red
4	Flat-surface retroreflective	Green
5	Exposed lens	White
6	Exposed lens	Red
8	Flat-surface retroreflective	Silver-white
9	Flat-surface retroreflective	Red
10	Flat-surface retroreflective	Green
11	Nonretroreflective	Green
12	Exposed lens	White
13	Nonretroreflective	Yellow
14	Flat-surface retroreflective	Silver-white
15	Exposed lens	Green
17	Nonretroreflective	Green
18	Nonretroreflective	Black
19	Nonretroreflective	Green
22	Flat-surface retroreflective	Blue
23	Flat-surface retroreflective	Yellow
24	Nonretroreflective	Orange
25	Exposed lens	Yellow
26	Flat-surface retroreflective	Yellow
27	Flat-surface retroreflective	Red
28	Flat-surface retroreflective	Silver-white
29	Exposed lens	Red
30	Exposed lens	White
31	Exposed lens	Silver-white
32	Exposed lens	Red
33	Exposed lens	Silver-white
34	Exposed lens	Red
35	Exposed lens	Silver-white
36	Exposed lens	Red
37	Exposed lens	Yellow
38	Exposed lens	Green
39	Exposed lens	Blue
40	Flat-surface retroreflective	Silver-white
41	Flat-surface retroreflective	Red

observations made on new and exposed facings. After each item, the applicable test method is noted.

- . . Reflective characteristics - Modified Texas 840-B.
- . . Color measurement - SwRI - Spectrophotometric.
- . . Bend test - THD Item 7081. 0.
- . . Tensile strength - ASTM-D 828.
- . . Elongation - ASTM-D 828.
- . . Adhesion-bond - SwRI/modified ASTM-D 903.
- . . Thermal tests - SwRI.
- . . Abrasion resistance - modified ASTM-D 968.
- . . Impact resistance - SwRI.
- . . Cleanability - SwRI.

B. Examination and Evaluation Methods

1. Photometric Evaluation of Sign-Facing Materials

a. Reflective Properties

All of the reflective-type materials that were placed on racks for exposure testing or which had been prepared for other physical testing were evaluated for reflective properties. Reflection data were obtained on samples of all new reflective materials representative of those used for testing; similar data were obtained on the samples after testing, for comparison. In the case of the panels exposed at San Antonio, data were taken at approximately two-month intervals during the period of exposure. The reflectance measurements were obtained using Southwest Research Institute's photometric tunnel.

Primarily, the data required were those indicated in Table II, Reflection Data Sheet. Reflective Intensity, R, was generally measured at divergence angles of 0. 2 and 0. 5 degrees, and at angles of incidence of -4, 0, 5, 10, 15, 20, 30, 40 and 50 degrees. Data from the reflection data sheets were used in producing summaries of the various tests performed.

Reflection data were also obtained for the purpose of evaluating the reflective property of sign facing under conditions of simulated rainfall and dew, and of appraising retroreflective test methods in view of variations in equipment and specifications.

References pertaining to the operation of equipment and methods used in photometric evaluation of reflective materials are:

- . . Federal Specification CCC-S-00320.
- . . MIL-R-13689A (cancelled in 1963).
- . . MIL-S-2639A.

TABLE II. REFLECTION DATA SHEET

Lab. Sample No. ______________ Date: ______________

Material:

Purpose:

Conditions:

A. Test Distance, feet (d) . . . . ______

B. Divergence Angle, degrees (0.1 to 2.0 in 0.1° increments) . ______

C. Sample Area, (sq. ft.) . . . . ______

Other Information:

Test Data:

Incidence Angle, Degrees	Meter Reading R_r	Reflective Intensity $CP/FC/ft^2$ R	Incidence Angle, Degrees	Meter Reading R_r	Reflective Intensity $CP/FC/ft^2$ R

. . Texas Highway Department Test Method Tex-840-B.
. . Federal Specification L-S-300 - Supersedes Federal CCC-S-00320 and includes MIL-R-13689A.
. . Federal Test Method Standard No. 141 (formerly Federal Specification TT-P-141 b.

Photometric Tunnel

Early in the program, a facility was designed and constructed to be used to determine the brightness of retroreflective materials in absolute units. A schematic illustration of the equipment is shown in Figure 6.

The apparatus is contained in a dark room 60 feet long, as shown in Figure 7. In this dark tunnel is mounted a light source (750-watt projector, suitably stopped) having a maximum lens diameter of two inches and capable of projecting a reasonably uniform circular beam of light on a surface normal to the axis of the beam. The projected beam is about 12 inches in diameter at a distance of 50 feet from the end of the projection lens. The illumination source is a tungsten lamp of 2850°K minimum color temperature.

In operation, the mean intensity of the projected circular beam is measured with a photomultiplier tube. The intensity of the incident light is kept as constant as possible during a test with the aid of a voltage regulator in the circuit of the projector lamp. In recognition of the variation of the intensity of the projected beam, the average of at least five measurements was used to establish an acceptable intensity value.

A test sample is held flat and rigid at a point 50 feet plus or minus 2 inches from the sample center to the center of the front projector lens and the receiver. It is centered and fastened on a vertical panel that can be rotated about a vertical axis in the plane of the sample. This varies the angle of incidence and is calibrated and adjustable to within $\pm$ 1/2°. The sample holder and the projector are rigidly placed so that the center of the projection lens is about 5 inches below the central normal of the sample. This mounting position prevents errors due to specular reflection. The projector is so located and adjusted to project the center of the circular beam to the center of the sample.

The light reflected from the sample is measured with a 931-A photomultiplier tube chromatically corrected to have a spectral response comparable to the average photopic human eye (a Kodak* Wratten Filter No. 106 is considered proper color correction), and a linear relationship in current output to incident light intensities up to 100 foot-candles. The maximum diameter of the receiver is 5/8 inch.

* Kodak is a commercial trademark.

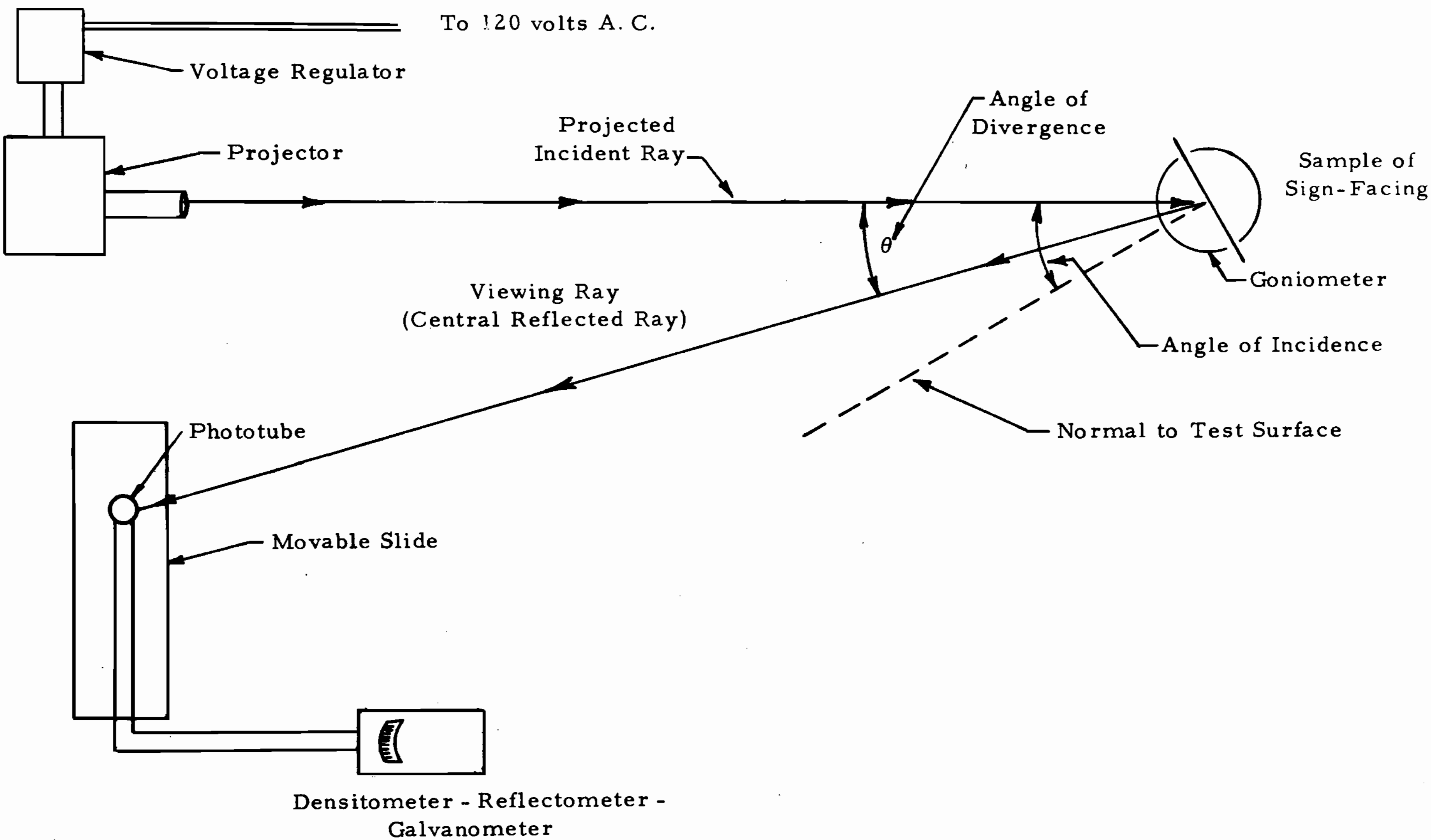


FIGURE 6. SCHEMATIC DIAGRAM OF PHOTOMETRIC TEST FACILITY

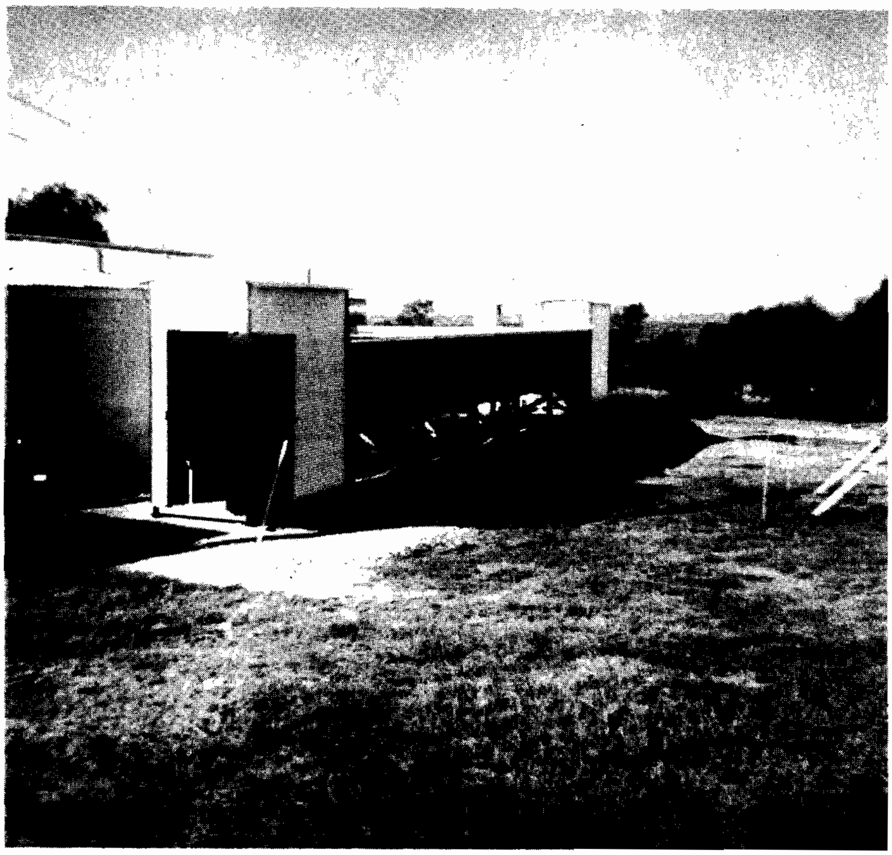


FIGURE 7. PHOTOMETRIC AND REFLECTION TESTING TUNNEL AT SOUTHWEST RESEARCH INSTITUTE

The current produced by the photomultiplier tube is measured by a modified densitometer-reflectometer, Model 12-A, manufactured by Macbeth Instrument Corporation. Meter readings can be converted to foot-candles by suitable calibration.

The phototube is mounted on a movable slide at a right angle to the incident beam, near the projector. The center of the aperture is placed at variable distances from the axis of the projecting lens system in such a way that at a given point on the horizontal traverse, the phototube receives a beam of divergent rays. The central axis forms the desired divergence angle with the central axis of the incident beam. The multiplier tube housing may be moved toward the projector to decrease the divergent angle (this is the angle between the projector, test panel and multiplier tube) or as far out as the traverse will allow to permit a maximum 2-degree divergent angle.

The entire photometer unit is mounted in a dark, black-walled room where stray reflections are reduced to a minimum. The rays never fall directly on the photomultiplier tube or at any point immediately in front of the plane of the tube face. In addition, the light projected on the sample outside of, but adjacent to, the 12-inch circle is less than 1% of the incident light.

Some difficulties encountered in the early operation of the equipment were found to be associated with experimental techniques. The entire system then was re-examined and modifications were made in the photometric set-up. The changes consisted of: 1) minor rewiring in the Macbeth densitometer, 2) provision of a smaller orifice for light passage into the photomultiplier tube, and 3) better shielding of the photomultiplier tube. The system also was arranged so that the vertical plane of the sample was 90° to the axis of the incident light beam. This resulted in specular gloss highlights at low angles of incidence, but readings were not made in this region when specular interference occurred.

It was late in the second quarterly period before reliable retroreflective measurements were obtained. Data in Table III give a comparison of results obtained at Southwest Research Institute and at Texas Highway Department Laboratory. The results obtained at Southwest Research Institute were not identical to those obtained on the same materials by the Texas Highway Department but were felt to be sufficiently close for purposes of this study. The values obtained in Texas Highway Department Laboratory were in close agreement with those obtained at several other laboratories. Results obtained were consistent from run to run on measurements made on all of the samples examined. Table IV lists the reflective intensity values of the various new, unexposed sign-facing materials for divergence angles of 0.2 degree, and Table V shows the values for angles of 0.5 degree.

TABLE III. COMPARISON OF PHOTOMETRIC RESULTS OBTAINED AT SOUTHWEST RESEARCH INSTITUTE AND AT TEXAS HIGHWAY DEPARTMENT LABORATORY

For Divergence Angle of 0.2 Degrees

Angle of Incidence,	Material Code Number, Reflective Intensity Values													
	1		2		3		8		9		14		15	
Degrees	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD
-4	15.4	--	17.0	--	12.6	--	48.0	--	5.9	--	98.8	--	17.6	--
0	15.4	--	17.0	--	--	--	--	--	--	--	102.7	--	19.8	--
1-1/2	--	14.8	--	17.9	--	8.28	--	58.0	--	5.07	--	110	--	23.1
5	15.4	--	17.0	--	11.9	--	47.6	--	5.8	--	94.7	--	17.2	--
10	15.3	14.8	16.7	17.3	11.6	7.76	32.6	35.2	4.8	3.42	94.7	107	11.7	13.8
15	14.8	14.5	15.7	16.2	11.0	7.14	18.6	16.6	2.2	1.93	90.5	95.2	4.4	6.0
20	14.3	14.1	14.5	14.8	9.5	6.31	7.5	6.52	1.2	0.97	84.3	82.8	1.22	2.0
30	12.6	12.4	9.5	9.42	5.5	3.73	0.72	0.83	0.23	0.17	48.8	47.6	0.15	0.24
40	10.7	10.7	6.9	7.35	1.6	1.38	0.13	0.14	0.07	0.35	19.3	16.2	0.05	0.07

For Divergence Angle of 0.5 Degrees

Angle of Incidence,	Material Code Number, Reflective Intensity Values													
	1		2		3		8		9		14		15	
Degrees	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD	SwRI	THD
-4	9.8	--	14.1	--	4.5	--	29.5	--	3.7	--	48.0	--	11.9	--
0	9.8	--	14.1	--	--	--	--	--	--	--	51.8	--	13.4	--
1-1/2	--	9.21	--	13.8	--	3.83	--	31.1	--	3.83	--	34.9	--	14.8
5	9.8	--	14.0	--	4.4	--	28.8	--	3.3	--	48.0	--	11.7	--
10	9.8	9.32	13.6	13.5	4.2	3.73	25.2	23.5	2.4	2.59	48.0	51.8	7.7	8.59
15	9.7	9.21	12.6	12.4	4.1	3.73	15.6	13.5	1.75	1.62	48.0	50.7	2.5	4.04
20	9.0	8.80	11.0	10.7	3.8	3.52	6.6	5.8	1.00	0.90	44.6	46.6	0.87	1.21
30	7.8	7.66	6.5	6.42	2.35	2.45	0.70	1.76	0.20	0.17	32.0	32.1	0.09	0.11
40	6.7	6.42	4.5	5.07	1.22	1.17	0.11	0.11	0.05	0.04	14.8	12.4	0.03	0.04

TABLE IV. REFLECTIVE INTENSITY VALUES OF NEW, UNEXPOSED SIGN-FACING MATERIALS FOR DIVERGENCE ANGLE OF 0.2 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1	2	3	4	5	6	8	9	10	12	14	15	22	23	27	28
-4	15.4	17.0	12.6	13.4	240.0	5.2	55.0	5.9	11.0	22.5	95.0	17.6	6.9	42.5	3.3	48.0
0	15.4	17.0	26.5	18.4	240.0	5.2	187.0	39.6	67.5	21.3	97.5	19.8	8.1	44.0	16.0	110.0
5	15.4	17.0	11.9	13.4	240.0	5.6	47.5	5.8	10.0	21.0	93.8	17.2	5.6	40.5	2.3	48.8
10	15.3	16.7	11.6	12.7	215.0	5.6	33.0	4.8	7.0	19.0	87.5	11.7	5.3	38.0	1.3	30.5
15	14.8	15.7	11.0	11.0	190.0	6.0	15.6	2.2	3.6	15.0	81.3	4.4	4.9	35.3	0.3	10.8
20	14.3	14.5	9.5	9.7	162.5	6.0	5.6	1.2	1.4	10.0	68.7	1.2	4.4	30.2	0.0	2.8
30	12.6	9.5	5.5	5.3	90.0	4.5	0.6	0.2	0.3	6.3	40.0	0.2	2.9	18.8	0.0	0.0
40	10.7	6.9	1.6	2.1	42.5	2.9	0.09	0.07	0.08	4.4	12.5	0.05	1.6	9.0	0.0	0.0

Angle of Incidence, Degrees	31	32	34	35	36	37	38	39	40	41
-4	172.5	10.0	4.6	208.0	11.0	100.0	35.0	11.0	16.3	1.5
0	172.0	10.5	4.8	208.0	11.0	105.0	37.5	10.0	37.5	6.3
5	177.0	10.0	4.8	208.0	10.4	105.0	35.0	9.0	14.5	0.9
10	182.0	8.8	4.6	212.0	9.5	100.0	42.5	8.5	11.3	0.7
15	187.0	7.0	4.3	242.0	7.9	92.0	30.0	7.5	4.3	NR
20	180.0	5.0	3.8	247.0	7.3	87.0	25.0	6.0	1.6	NR
30	127.0	2.6	2.5	173.0	4.8	63.0	15.0	3.5	NR	NR
40	70.0	1.1	1.5	60.0	3.3	37.5	7.5	2.0	NR	NR

TABLE V. REFLECTIVE INTENSITY VALUES OF NEW, UNEXPOSED SIGN-FACING MATERIALS FOR DIVERGENCE ANGLE OF 0.5 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1	2	3	4	5	6	8	9	10	12	14	15	22	23	27	28
-4	9.8	14.1	4.5	5.3	106.3	2.4	25.0	3.7	6.3	6.3	45.0	11.9	3.5	19.0	1.4	27.5
0	9.8	14.1	19.1	9.9	102.5	2.5	106.3	43.8	35.0	6.8	47.5	13.4	4.8	19.8	21.3	85.0
5	9.8	14.0	4.4	5.3	105.0	2.5	24.8	3.3	4.5	6.8	42.5	11.7	3.0	17.5	1.3	25.0
10	9.8	13.6	4.2	5.0	107.5	2.6	19.8	2.4	3.6	6.5	42.5	7.7	2.8	17.0	0.8	20.3
15	9.7	12.6	4.1	4.8	110.0	3.0	11.9	1.8	2.3	5.6	40.0	2.5	2.5	15.8	--	8.8
20	9.0	11.0	3.8	4.3	105.0	3.1	6.0	1.0	1.0	4.0	37.5	0.9	2.3	14.8	--	2.3
30	7.8	6.5	2.4	2.5	68.8	2.5	1.1	0.2	0.3	2.6	25.0	0.1	1.7	11.5	--	--
40	6.7	4.5	1.2	1.5	30.0	2.1	0.5	0.05	0.02	2.1	10.0	0.03	0.9	6.2	--	--

Angle of Incidence, Degrees	31	32	34	35	36	37	38	39	40	41
-4	30.0	5.0	4.5	98.0	10.6	55.0	13.8	2.5	8.5	0.35
0	29.5	5.0	4.7	98.0	11.0	58.0	15.0	2.8	2.8	5.80
5	26.5	4.8	4.5	98.0	10.4	58.0	13.8	2.0	6.3	0.20
10	25.8	4.3	4.3	98.0	10.0	63.0	13.8	2.0	4.5	--
15	34.0	3.6	3.7	105.0	7.9	67.5	12.5	1.8	2.4	--
20	52.5	2.8	3.1	123.0	--	80.0	10.0	1.3	0.8	--
30	76.3	1.3	1.9	208.0	--	80.0	5.0	--	--	--
40	55.0	0.5	1.0	190.0	--	63.0	1.8	--	--	--

Wet Reflectance Tests

Provision was made to run reflectance tests under conditions of rainfall and dew or mist. The goniometer panel holder was modified by the addition of a water spray head designed and installed according to Federal Specification LS-300. In operation, the water flow rate could be adjusted to simulate various rates of rainfall. In order to simulate dew conditions, a tentative test method was developed. With the tunnel instrumentation system operating, water vapor was directed against test panel faces until a water film judged similar to dew was produced. Measurement of reflective intensity was made immediately thereafter. In order to obtain a mean value for a single specimen, several measurements were made by the above method. Results were averaged, even though values from one run to another were in good agreement.

New materials and test panels that had been subjected to seven months' outdoor exposure were examined in this work. Results obtained are shown later in the section titled "Exposure Tests." The "dew" condition usually caused larger reductions in reflective values than did the flooded condition which simulated rainfall. Material 31 had a reflective value of 29.5 when flooded, and 25.3 with a "dew" film. Material 32 reflected more light under "dew" conditions than it did when flooded. Materials least affected by wet conditions were Nos. 3, 9, 10 and 14.

b. Color Measurements

In general, chemical and physical changes that take place in sign-facing materials may be accompanied by changes in color. Color changes can be indicative of deterioration due to weathering, as well as to physical factors such as scratches, dirt, etc. A purpose in this study was to observe if, and to what extent, color changes might be indicative of stability or lack of it under conditions of exposure to weather and to the effects of various tests. The standard or basic method for the determination and description of color is with the use of the spectrophotometer and the resulting spectrophotometer curve. The instrument used in this study was a Bausch & Lomb Spectronic 20 Colorimeter-Spectrophotometer, with a Color Analyzer reflectance attachment.

Color may be expressed in terms of the intensity of light of all visible wave lengths reflected from an object. Although spectrophotometric curves effectively define color, this manner of presentation is not always the most convenient. From such data, values of X, Y and Z (Tristimulus Values) plus the trichromatic coefficients, x and y, may be calculated. The values of x and y can be used to define the dominant wave length and color saturation. The value of Y, which relates to brightness, when used with x and y coefficients gives a good concept of color and color differences.

Spectrophotometer data were obtained on most of the sign-facing samples before and after many of the tests, reduced to values of x, y, and Y, and tabulated. Table VI lists the new, unexposed facing materials with the CIE chromaticity coordinates x and y, the brightness factor Y, and the dominant wave length.

2. Physical and Mechanical Properties

Standard tests used to determine the physical and mechanical properties of plastics provide little more than relative ratings. Partly because they are conducted under ideal conditions and usually by separate tests, the data they provide do not tell how facing materials will perform under service conditions. However, in order to arrive at some standard basis for comparison, physical and mechanical tests were performed on sign-facing materials. The following outline indicates the various tests and evaluations that were conducted in studies of physical properties; descriptions of procedures and equipment and results of the work follow the outline.

a. Abrasion

1) Abrasion caused by elements, sand, etc.
2) Abrasion causedby cleaning.

b. Adhesion

1) Protective backing paper.
2) Adhesion to panel backing material.
   a) 48-hour aging.

c. Bend Tests (Flexibility)

1) At room temperature.

d. Thermal Stability

1) Elevated temperature (180 - 200°F).
2) Sub-freezing temperatures.

e. Cleanability

1) Standard test - detergents, etc.
2) Color measurements, microscopic examination, reflection tests before and after cleaning.

f. Impact Resistance

1) Effect of impact on facing.
2) Effect of backing material on impact resistance of facing.

TABLE VI. SPECTROPHOTOMETER VALUES OF NEW, UNEXPOSED SIGN-FACING MATERIALS

	Sample Code No.	Y	x	y	Dominant Wave Length
White	1	76.38	0.324	0.333	572
	2	84.05	0.314	0.329	545
	5	50.49	0.315	0.318	595
	8	46.66	0.323	0.340	570
	12	74.69	0.314	0.316	585
	14	60.71	0.337	0.374	566
	28	41.76	0.338	0.349	576
	31	59.32	0.313	0.320	574
	33	62.63	0.311	0.323	558
	35	59.76	0.313	0.319	569
	40	42.88	0.320	0.336	569
Red	3	9.66	0.561	0.314	616
	6	13.68	0.480	0.332	608
	9	10.83	0.530	0.334	590
	27	11.99	0.391	0.350	590
	29	11.28	0.434	0.314	630
	32	14.86	0.417	0.329	608
	34	14.16	0.426	0.329	606
	36	18.82	0.409	0.318	613
	41	9.02	0.517	0.318	615
Yellow	23	37.94	0.486	0.447	582
	24	26.09	0.488	0.348	600
	25	54.47	0.479	0.442	581
	26	27.96	0.497	0.424	585
	37	46.76	0.398	0.433	574
Green	4	12.74	0.197	0.414	501
	10	16.19	0.215	0.394	500
	11	16.60	0.252	0.368	507
	15	16.91	0.230	0.384	500
	17	15.72	0.233	0.363	497
	19	20.24	0.270	0.338	497
	38	20.35	0.274	0.363	506
Blue	22	6.14	0.213	0.199	473
	39	18.39	0.246	0.282	485

g. Elongation and Tensile Strength

1) Sheeting only tested for elongation and tensile strength.

h. General Visual Qualities

1) Microscopic examination.

a. Abrasion

Optical clarity of the overlying plastic is a prime requisite for the proper functioning of the reflex properties of the lens elements in plastics of the flat-surface type, and also for some of the oversprayed exposed-lens or beads-on-binder materials. Any manner of degradation of the surface will have an influence on this function and usually is manifested by a decrease in reflective intensity. Such factors as abrasion, dirt, cracking or other surface defects can seriously impair the reflective quality of the sign-facing material.

Abrasion of the surface may be caused by the impact of wind-blown impurities such as dust, soot, sand and chemicals. More often, the surface is abraded and dulled by improper cleaning techniques.

To evaluate the abradability of sign-facing materials, a modified standard abrasion test for coatings -- the falling-sand method, ASTM Designation D968-51 -- was employed. A device for use in this work was constructed as shown in Figure 8. In this test, standard sand was caused to fall vertically through a metal tube 36 inches in length by 3/4 inch in diameter. The falling sand impinged on the specimen, which was located one inch below the lower end of the tube and tilted 45 degrees from the tube axis.

The standard test requires that the effects of abrasion be evaluated in terms of thickness of coating removed. In this work, the influence of the abrasion was estimated in terms of the CIE tristimulus color coordinates, as shown in Table VII. The principal index appeared to be the brightness coefficient, Y. Examination of Table VII shows that abrasion usually caused an increase in the Y coefficient, i. e. , the sign facing appeared brighter in diffuse reflection after abrasion than before. The maximum brightness would be 100 with white diffuse reflectors. Abrasion tended to convert the surfaces to diffuse reflectors.

An example of the changes in the brightness factor, Y, with severity of abrasion of flat-surface sheeting is shown in Figure 9. The brightness increased rapidly with the initial mild fall of abrasion sand. With continued abrasion, the brightness began to diminish. Another example of abrasion on a different

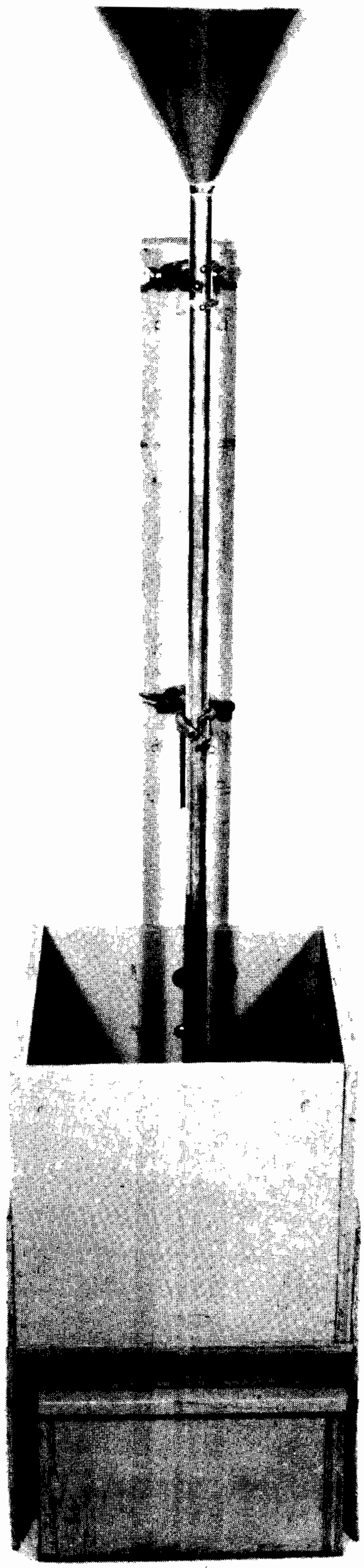


FIGURE 8. MODIFIED STANDARD ABRASION TEST UNIT FOR DETERMINING ABRASION-RESISTANCE OF SIGN-FACING MATERIALS.

TABLE VII. ABRASION RESISTANCE OF SIGN FACINGS

Material Code	Vol. of Sand in Milliliters*	Brightness Unabraded Y	Brightness Abraded Y	Percent Change
1	100,000	91.88	88.84	- 3.31
15	1,000	18.70	21.55	+13.22
11	400	19.33	19.62	+ 1.48
12	400	75.00	74.49	- 0.69
17	400	19.17	20.26	+ 5.38
19	400	15.74	16.95	+ 7.14
23	400	41.19	44.00	+ 6.39
25	400	54.37	55.87	+ 2.68
29	400	11.53	12.37	+ 6.79
2	300	80.70	83.47	+ 3.32
4	200	15.27	16.94	+ 9.86
5	200	59.97	66.79	+10.20
10	200	18.46	22.43	+17.71
24	200	43.81	29.35	-33.01
3	100	11.97	13.45	+11.00
8	100	41.94	53.65	+21.83
9	100	13.03	16.29	+20.01
14	100	61.68	62.52	+ 1.34
22	100	10.63	11.50	+11.04
26	100	36.23	66.96	+45.89
27	100	10.72	12.37	+13.34
28	100	40.07	50.08	+19.99
30	100	53.70	56.02	+ 4.14
6	100	12.55	16.16	+22.40

* Note: The volume of sand used was approximately the minimum required to cause a definite visual change of appearance in daylight.

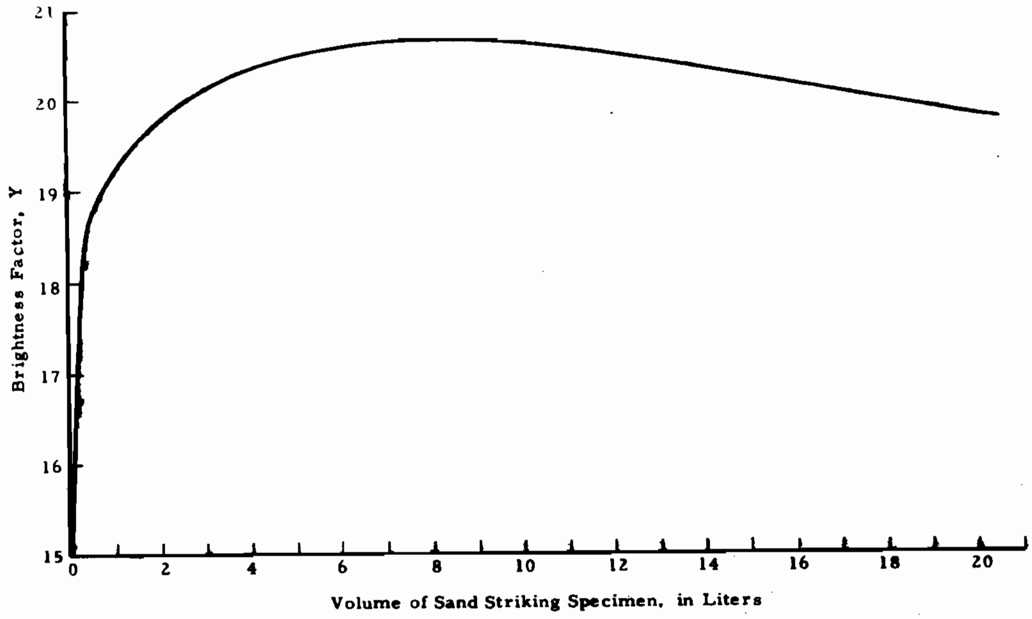


FIGURE 9. EXAMPLE OF THE INFLUENCE OF CONTINUED ABRASION (USING ASTM STANDARD SAND) OF FLAT-SURFACE SHEETING ON BRIGHTNESS FACTOR, Y

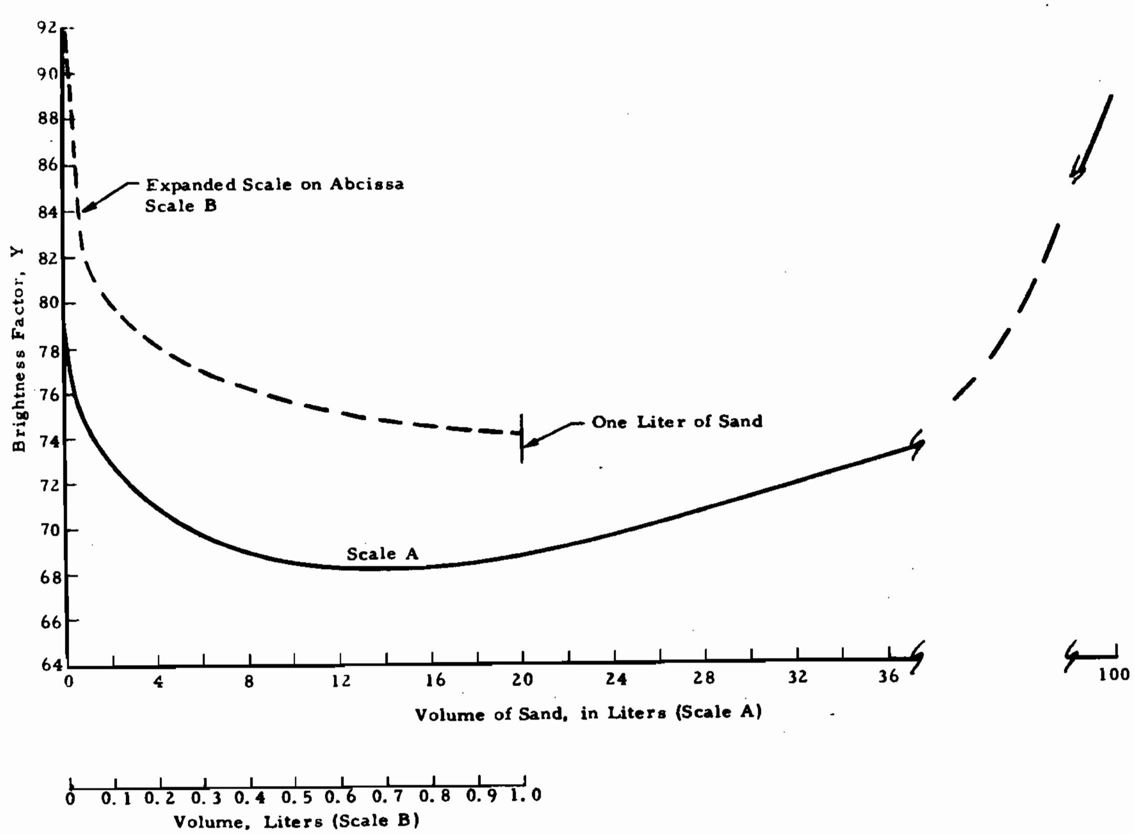


FIGURE 10. EXAMPLE OF CHANGE IN BRIGHTNESS FACTOR, Y, WITH PROGRESSIVE SAND ABRASION, USING ASTM STANDARD SAND. SAMPLE: CODE 1

type of sign surface is shown in Figure 10. In this case, initial but relatively small amounts of impinging sand rapidly diminished the Y factor. The minimum value occurred at about 12 liters of sand, after which the Y factor increased, approaching the initial, unabraded factor with 100 liters of sand.

In these tests, the abrasion was continued until an obvious visual change of appearance, in daylight, occurred. The amount of sand required for this is shown in Table VII. Of major importance was the effect of abrasion on nighttime retroreflective brightness. The abraded areas were too small to permit measurements of reflective intensity. However, the abraded surfaces were "blacked-out" when viewed under retroreflective conditions, as shown in Figure 11. Abraded panels, when viewed with small divergence angles with a directed light beam, were rendered more nonretroreflective than were wet signs which are vulnerable to "black-out" due to moisture.

The data in Table VII refer to "abradability", or ease of abrasion, and have no relation to the amount of abrasion required to produce night "black-out." The degree of abrasion required to produce permanent night "black-out" would be less than that indicated. Flat-surface sheeting was particularly vulnerable to abrasion damage of this sort, but could usually be restored by a thin surface overcoat. Open lens types were less vulnerable than flat-surface facings.

b. Adhesion

In signing materials and structures, there are two types of bonding that may be of interest. For exposed bead surfaces, the adequacy with which the beads are bonded to the matrix is of importance. The bond between the substrate or backing and the sign facing is of primary interest in sign surfaces faced with sheeting.

The degree of bonding of adhesive sheeting to plywood, aluminum, and steel substrates was observed, using a peel test. For this test, the sheeting was bonded to the backing, and the force required to remove the sheeting was measured. An Instron testing machine was used, fitted with tensile grips. The backing was attached to the upper grip, and the sheeting was gripped and peeled back by the lower chuck, and the performance executed as a tensile test. The values recorded 48 hours after the application of pressure-sensitive sheeting included maximum, minimum and mean values in pounds per inch width of sheeting; these were measured for samples bonded to backings of aluminum, galvanized steel, and plastic-coated high-density plywood.

There was little variation in the force required to remove the sheeting from different types of backing. Peel force required for separation ranged from a minimum of one pound per inch width to a maximum of just over 9 pounds. There appeared to be little or no correlation between the type of adhesive, type of sheeting and the bond strength. Some of the pressure-sensitive adhesives were

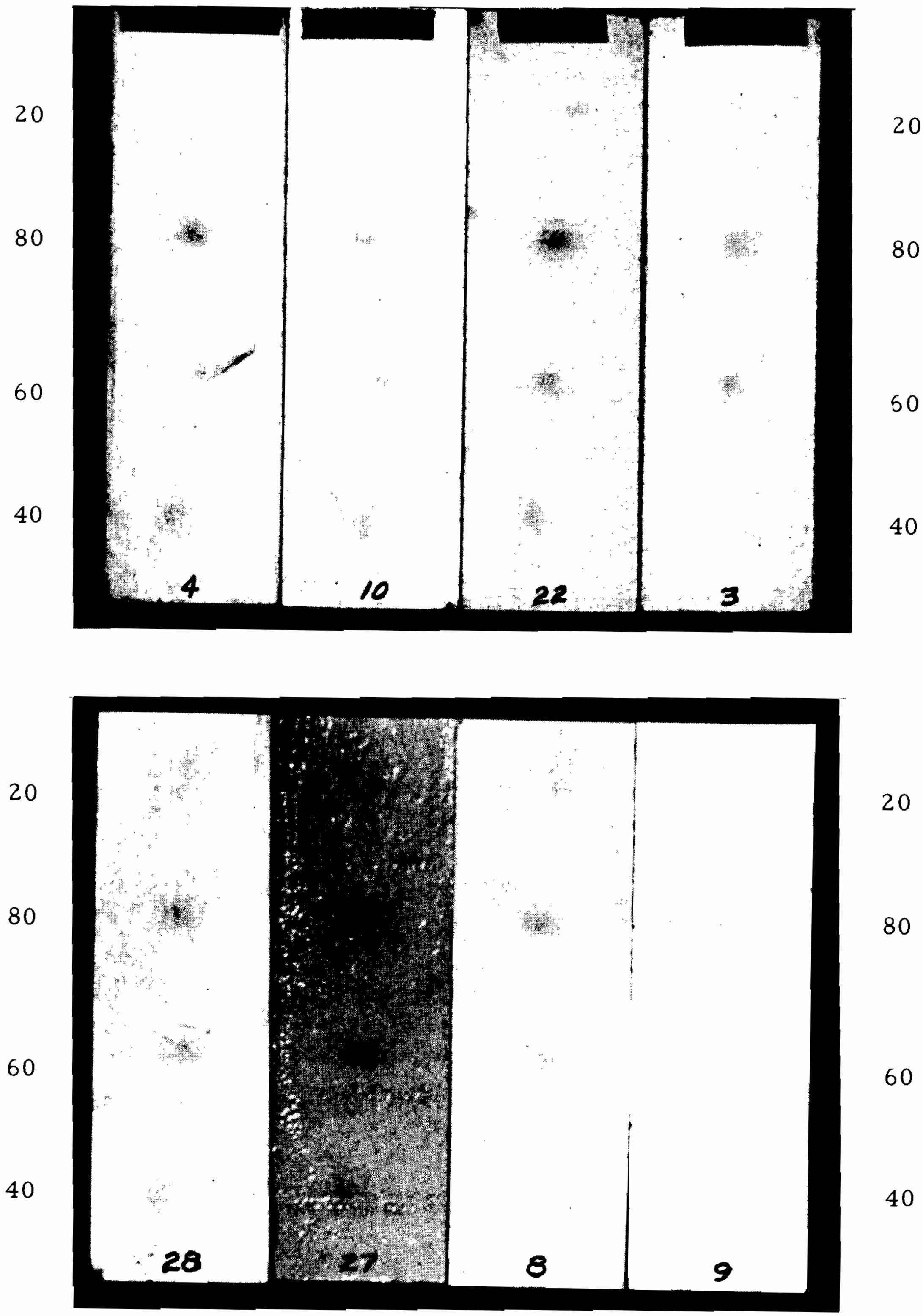


FIGURE 11. RESULTS OF LABORATORY ABRASION-RESISTANCE TESTS ON SELECTED SIGN-FACING MATERIAL. MATERIAL CODE AS SHOWN AT BOTTOM OF EACH PANEL. QUANTITY OF SAND IN MILLILITERS AT RATE OF 100 ml PER SECOND.

apparently bonded as strongly as the thermally bonded.

The relative degree of bonding of glass beads to the matrix in exposed-lens and beads-on-paint types could be observed by microscopic study. Poorly bonded beads were found to have detached from the matrix and had left smooth replicas of the bead surface. This was a minor defect found in most of the open-lens type of facing. Service exposure, rough handling, and impact damage were found to be primary causes of loss of beads, but this was not necessarily because of poorly bonded beads.

In some of the flat-surface sheeting samples that were on outdoor exposure, it appeared that early failure was due to the development of unfavorable microstress patterns between beads and matrix. Microscopic cracks were evident in some of the materials after less than three months' exposure. These appeared first as a separation of the matrix from the beads and then progressed to the surface.

c. Flexibility (Bend Tests)

Various sheeting samples were subjected to a bend test to determine if severe bending and flexing would cause permanent physical damage to the sheeting. The test was performed as specified in Texas Highway Department Item 7080, "Flat Surface Flexible Reflective Sheeting," Section 5. a. (1) and subsequent special specifications, where applicable.

The sheeting was applied, according to manufacturers' recommendations, to cleaned and etched 0.015-inch x 2-inch x 8-inch aluminum. Each sample was then given a 90-degree bend around a 3/4-inch mandrel. After visual examination to detect any effects caused by the 90-degree bend, the bent specimen was flattened out and again examined. The results of the test indicated that no serious problems exist insofar as the flexibility of sign-facing materials is concerned. None of the materials examined was damaged severely by the 90-degree bend. Slight puckering of the adhesive was noted in a few specimens, but only after the bent sample was returned to a flat condition.

d. Thermal Stability

1) Elevated Temperature

A test was devised to determine the effect of heating on samples of various sheeting facing materials. The sheeting was applied to a 0.015-inch aluminum coupon 2 inches x 8 inches in size. Each sample was examined for surface conditions, adhesion, brittleness and other features prior to heating. After 30 minutes' exposure to a controlled temperature of 200°F, the sample was examined while hot to determine if softening had occurred. On cooling, the sample was again examined to detect effects of the heat/cool cycle. Visual observations of samples after the thermal test are given in Table VIII.

TABLE VIII. EFFECTS OF HEATING VARIOUS SIGN-FACING SAMPLES AT 200°F FOR 30 MINUTES

Material Code	Visual Observations of Samples after Thermal Test
1	No effect.
2	No effect.
3	Sheeting and adhesive soft while hot. Sheeting became brittle after cooling.
4	Sheeting became slightly brittle after cooling.
5	Binder and paint harder after treatment.
6	Binder and paint harder after treatment.
8	Adhesive softened.
9	Adhesive softened.
10	Adhesive softened.
11	No effect.
12	Adhesive softened.
14	No effect.
15	No effect.
17	Sheeting shrank; adhesive became brittle after cooling.
19	Slight softening of sheeting and adhesive was noted.
22	Sheeting bond to panel became stronger; sheeting brittle after cooling.
23	Adhesive softened. Sheeting became slightly brittle after cooling.
24	Sheeting and adhesive softened.
25	Adhesive softened.
26	Adhesive softened. Puckering of sheeting had healed.
27	Adhesive softened.
28	Adhesive softened.
29	No effect.
30	No effect.
31	No effect.
32	No effect.

2) Freeze Tests

A rapid test method was used to determine the freeze-resistance of sign-facing materials. The facing was applied to standard 1-inch x 8-inch, 0.015-inch aluminum blanks and immersed in a container which was maintained at 20°F. Each material in turn was quickly removed for testing the effect of sub-freezing conditions on the facing and on the adhesive. The results are tabulated in Table IX.

It is evident that freezing temperatures may be a major cause of sign deterioration in those areas subject to low temperatures. In areas of relatively mild winters, but subject to daily fluctuations from below freezing to above, the adverse effects most likely would be accelerated. Some of the materials were tested after having been held at minus 20°F for thirty minutes. In all cases except Material Code 17, the facing and adhesive were so brittle that only a slight impact was required to completely shatter the material.

e. Cleanability

For determination of the cleanability of sign-facing materials, a simple test was performed on specimens that had been subjected to outdoor exposure at San Antonio. The test was made only on facings which had been continuously exposed for at least 100 days or more. Prior to cleaning, none of the specimens had been cleaned in any way except by normal rainfall.

The detergent solution used was very similar to that recommended in Texas Highway Department "Specification for Synthetic Liquid Detergent, Nonionic," September 1964, and "Specification for Sign Cleaning Detergent," File Nos. 9.206 and 9.123, respectively. Each exposure panel was immersed in the detergent, agitated for 30 seconds, and then rinsed with running tap-water. After drying, the facing was checked for color and brightness changes on the spectrophotometer. Table X gives the chromaticity brightness factor, Y, before and after cleaning. Also included are the measurements on the reflective intensity values, R, for 0.2 degree divergence and -4 degree incidence angle.

Increase or decrease in the brightness factor, Y, was used as a criterion for judging the effects of detergent cleansing on the materials. As indicated in Table X, all of the facing materials exhibited a higher "Y" reading after cleaning. The increase in brightness on the various panels ranged from less than 1 percent to about 35 percent, as in the case of Material No. 3. These data are indicative of the extent to which various facings were affected by the cleaning techniques. The Y factor, relating to diffuse reflection, is not an indication of retroreflective brightness. Determination of cleanability must also include measurement of photometric reflective values to show the effects on retroreflectivity.

TABLE IX. EFFECTS OF LOW-TEMPERATURE (20° F) EXPOSURE ON SIGN-FACING MATERIALS

Material Code	Effect on Facing Material	Effect on Adhesive	Effect on Bonding
2	Brittle - breaks easily	None	None
3	Brittle - breaks easily	None	None
4	Brittle - breaks easily	Separates from overlay	Some loss of bonding
8	Brittle - breaks easily	Becomes non-adhesive	Loss of bonding
9	Brittle - breaks easily	None	None
10	Brittle - breaks easily	Slightly brittle	Loss of bonding
12	Slight flexibility remains	None	None
14	Brittle - breaks easily	Brittle - separates and breaks easily	Some loss of bonding
15	Brittle - breaks easily	Brittle - separates and breaks easily	Some loss of bonding
17	Remains flexible	Becomes non-adhesive	Loss of bonding
22	Brittle - breaks easily	None	None
23	Brittle - breaks easily	Becomes brittle	Some loss of bonding
25	Remains flexible	Slightly brittle	Loss of bonding
26	Brittle - breaks easily	Slightly brittle	Loss of bonding

TABLE X. DATA SHOWING BRIGHTNESS AND REFLECTIVE-INTENSITY VALUES FOR SIGN FACING MATERIALS BEFORE AND AFTER EXPOSURE AND CLEANING

Material Code No.	Days of Exposure	Unexposed, As New		Exposed, As Exposed		Exposed, Cleaned	
		Y	R	Y	R	Y	R
1	140	76.38	15.4	70.27	9.3	70.52	8.12
2	107	84.05	17.0	74.43	12.0	76.16	11.5
3	107	9.66	12.6	11.16	6.3	15.04	5.5
4	140	12.74	13.4	13.03	12.8	16.01	12.8
8	126	46.66	55.0	48.40	47.5	51.29	42.0
9	126	10.83	5.9	13.60	3.3	16.84	3.0
10	126	16.19	11.0	17.07	7.5	19.05	6.3
11	140	16.60	NR	17.17	NR	20.14	NR
12	135	74.69	22.5	71.13	27.5	74.34	*
14	141	58.89	95.0	59.53	81.3	59.88	70.0
14	101	60.71	95.0	56.01	80.0	57.52	80.0
15	141	16.91	17.6	16.98	10.5	20.40	11.3
15	101	21.72	17.6	17.44	12.5	20.59	16.5
17	135	15.72	NR	17.68	NR	20.20	NR
22	101	6.14	6.9	8.24	3.8	10.87	4.6
23	101	37.94	45.0	36.77	42.5	39.29	42.5

Note: Y is the chromatic coefficient or brightness factor and denotes degree of whiteness.
R is the reflective intensity in candle power/foot-candle/$ft.^2$ and is given for 0.2 degree divergence and -4 degree incidence angle.
NR indicates that no reflective intensity reading was obtained on nonreflective materials.
* no reflection - all beads lost during exposure.

As shown in Table X, the reflective intensity values increased after washing only for Materials Nos. 15 and 22. All of the others either decreased or remained the same after washing.

Analysis of data has indicated that, in many of the types of facing material, there is a progressive lightening or whitening of the color during outdoor exposure, and simple cleaning of the facing increases the phenomenon. Degradation of the reflective properties during exposure is evident from a study of the data, and further deterioration in most facings has resulted from the cleaning process.

f. Impact Resistance

Field studies revealed that in some locations, a predominant factor in sign damage was impact from gravel and various other objects. The ability of sign materials to withstand impact forces without suffering significant damage becomes of practical importance. Studies were made for the purpose of establishing the order of impact energies required to rupture various types of sign-facing materials that were applied to backings.

The test used consisted of causing a steel sphere weighing 2-1/2 pounds to fall freely and strike the test surface. Successively greater falling distances were employed until the sign facing ruptured or cracked. Test panels were mounted on a rigid base consisting of a steel plate one inch thick by one foot square. The apparatus is shown in Figure 12.

The various sign facings were bonded to standard backing materials: plastic-coated high-density plywood, aluminum, and galvanized steel. It soon was evident that with steel or aluminum backings mounted on the rigid support, no apparent damage resulted from the impact of the steel sphere falling from several feet. The first damage noted was that of a permanent dimple or dent in the metal at the point of impact. In no case, however, was the deformation sufficient to rupture the sign facing.

High-density plywood backing was easily deformed, and rupture of the sign facing occurred. The force required to crack or rupture sign facings of various types was found to be in excess of that produced by 0. 5 foot-pound impacts. Among the facings examined, five (5) failed between 0. 6 and 0. 7 foot-pounds, and eleven (11) failed at impact values in the range of 1 to 4. 6 foot-pounds. Only two (2) facings did not fail when subjected to impacts producing a force of 7. 5 foot-pounds.

If the impact is carried out on samples not supported on a rigid anvil, as is the case with actual signs, the backing may be damaged by fracture in the case of plywood, and deformation or denting in the case of steel and aluminum. Samples of sign materials mounted on steel and aluminum were distorted or bent in

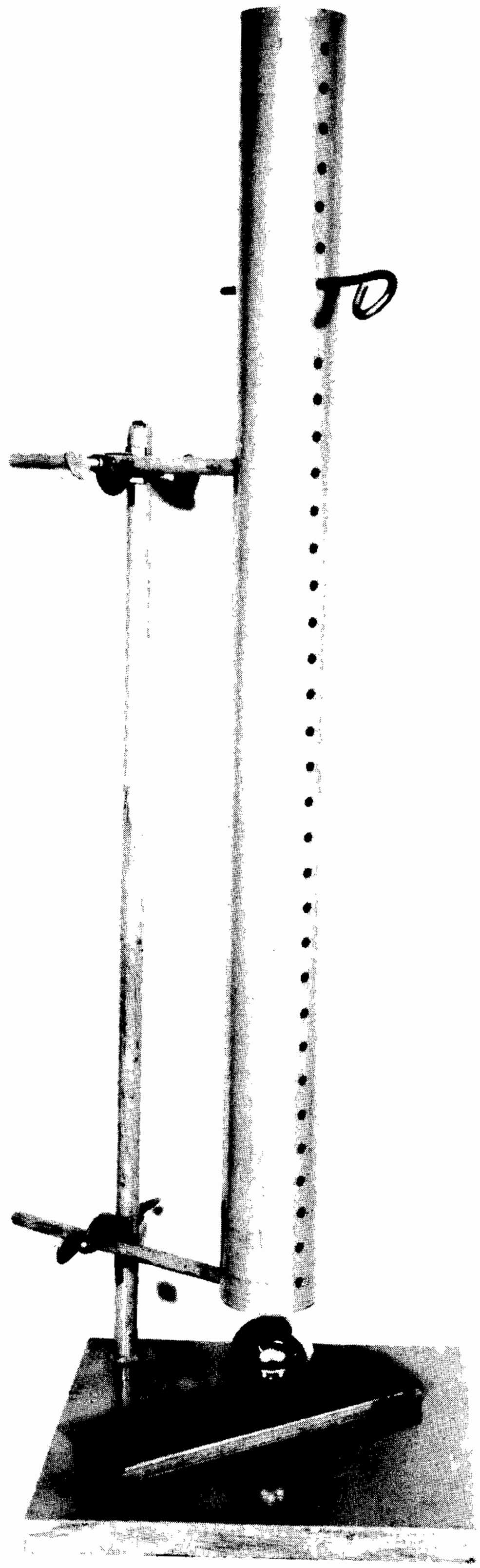


FIGURE 12. DROP-WEIGHT IMPACT TEST UNIT

laboratory tests, but cracking of the facing was not observed. Plywood, on the other hand, was cracked and splintered as shown in Figure 13 when the sign surface was struck with blows of approximately 6.0 ft-lb as produced by the 2-1/2-pound steel sphere.

g. Elongation and Tensile Strength

The use of tensile and elongation tests as an aid to characterizing sign-facing materials was considered to be of dubious value. However, these tests were conducted with an Instron testing machine, shown in Figure 14, to obtain information on the elongation and tensile strengths of a number of the materials. With this apparatus it was possible to accurately measure stress and strain properties of strips of sheeting which were 1/2 inch wide by 6 inches long.

A summary of the mechanical-properties data is given in Table XI. These data were not subject to satisfactory interpretation, and no conclusions have been drawn concerning them. The variance between maximum and minimum strengths of the various materials is very great. The influence of temperature on the different materials also covers a broad range.

An explanation of the terms used in Table XI may be helpful. The heading of the first column, "Material," refers to the code numbers in the column. In the second column are the laboratory specimen numbers. Test temperatures were 75° or 140°, in Fahrenheit. In the fourth column is listed the stress-strain curve type, which in turn designates which of the curves in Figure 15 most nearly applies in each case. "Stress" refers to tensile loading in psi, and "strain" designates linear displacement or stretch due to the applied load.

Referring to Figure 15, the straightest portion of the curves from the origin to the break toward a horizontal curve generally is indicative of reversible strain. The slope would be proportional to the elasticity. The more horizontal portions of the curves represent irreversible stretch. The vertical lines at the far right in either case represent failure by rupture.

Yield, psi, in column 5 refers to the stress required to cause permanent stretch. Maximum psi is simply the maximum stress that the specimen supported before failure. In column 7, the breaking load is listed in three instances. In some cases, such as are shown in Figure 15, type II curve, it appears that the stress at rupture (at the far right) is smaller than the maximum psi (the break at the far left). This is the value given in column 7. What happens is that after the yield point was reached (column 5), the cross section of the specimen continually was reduced, as was the load. Since the change in dimension was not taken into account, the real psi at failure was not reported. This was not computed because the cross section at the time of failure was not known.

The data in columns 8 and 9 refer to the stretch caused by the applied load. The "Crosshead Extension" was the apparent elongation read on the

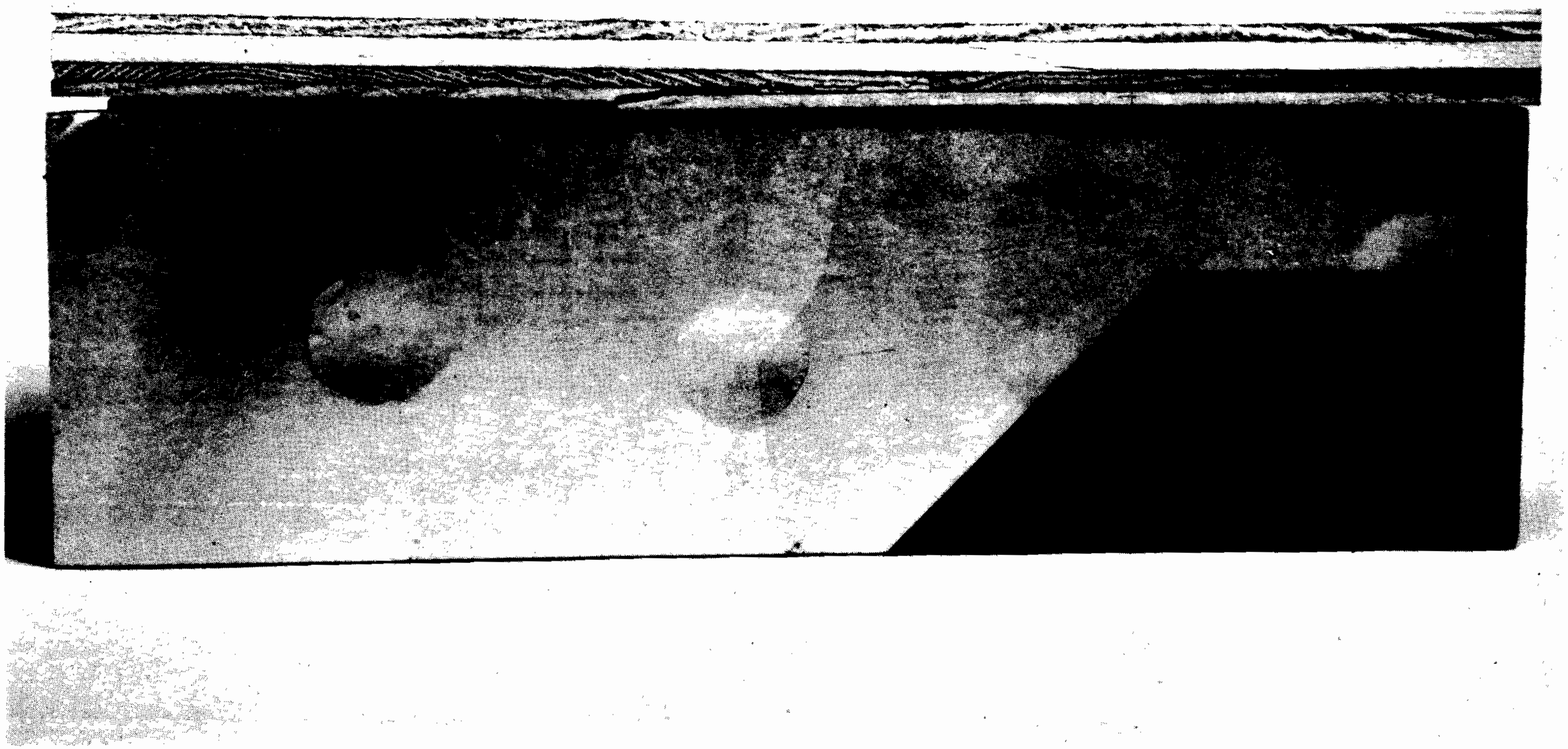


FIGURE 13. RESULTS OF LABORATORY IMPACT TEST ON REFLECTIVE SIGN-FACING MATERIAL APPLIED TO HIGH-DENSITY PLYWOOD. BALL DROPPED FROM HEIGHT OF 28 INCHES. CENTER IMPACT WAS MADE WITH ENDS OF PANEL ON SUPPORTS.

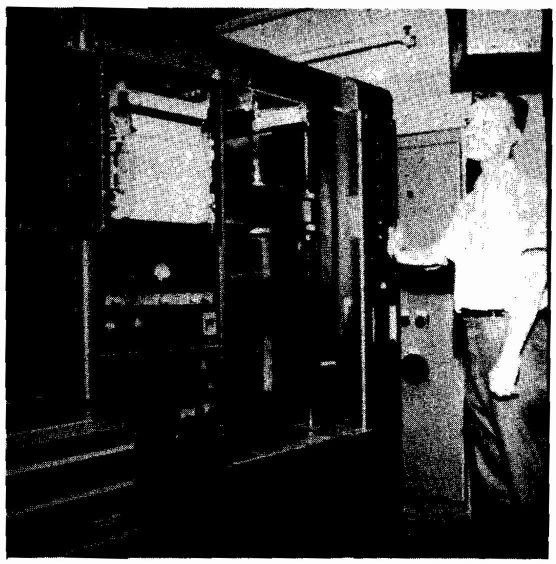


FIGURE 14. INSTRON TESTING MACHINE

TABLE XI. SIGN-FACING MATERIAL TENSILE TEST RESULTS

Material	Specimen Numbers	Test Temperature	Stress-Strain Curve-Class	Yield PSI	Maximum PSI	Breaking Load	Crosshead Extension	Total Elongation	%Elongation in 4 inches	Load at first crack
14	339 344	75°	I	440	830		1.223	0.566	14.2	
2	345 347	75°	I	220	500		1.616	0.630	15.8	
2	384 386	140°	IV		300	130	1.785			σ 280 ε 0.2
4	348 350	75°	I	350	590		2.038	0.536	13.4	
4	381 383	140°	III		290	200	2.012			σ 290 ε 0.25
8	351 353	75°	I	1800	2300		1.761	1.090	27.2	
8	378 380	140°	I	340	1028		1.025	0.598	15.0	
9	354 356	75°	I	1520	2110		2.521	1.809	45.2	
9	375 377	140°	I	470	1270		2.003	1.440	36.0	
10	357 359	75°	I	1570	2200		2.373	1.744	43.6	
10	372 374	140°	I	370	1340		2.067	1.490	37.3	
11	363 365	75°	I	2250	3740		2.516	1.789	44.7	
11	366 368	140°	I	800	3340		3.36	2.603	65.1	
13	360 362	75°	II		1750	1560	0.827	0.456	11.4	
13	369 371	140°	I	125	614		4.958	4.090	102.5	

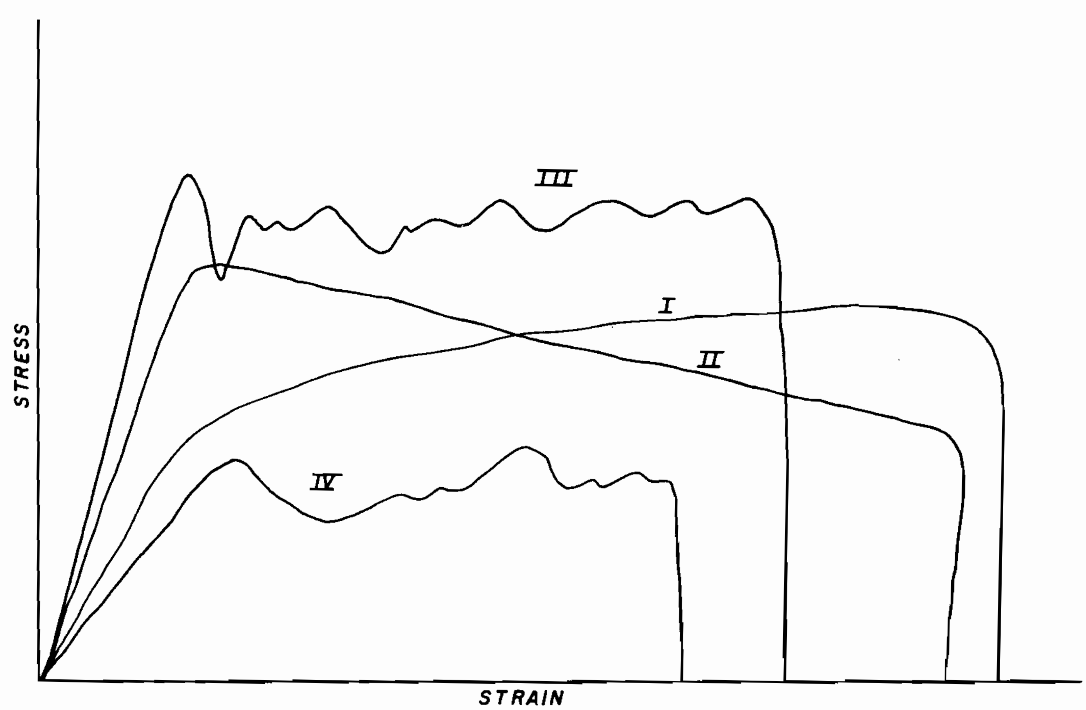


FIGURE 15. TYPICAL STRESS-STRAIN CURVES

machine at the time of failure. In the next column, "Total Elongation" is the total elongation after removal of load -- the permanent stretch. In column 10, "% Elongation in 4 Inches" gives the total elongation at failure in percent of the specimen length.

In the last column, the load -- in terms of psi causing the first visible crack -- is given. Directly below the load is given the strain at which cracking or tearing first appeared.

h. General Visual and Microscopic Qualities

Throughout the program, macroscopic and microscopic examinations were made on sign-facing materials. New materials were checked for general visual uniformity of color, fabrication defects and brightness. Close inspection revealed a number of samples which had a noticeable lack of uniformity, but when viewed in the photometric tunnel with the unaided eye and a flashlight, the irregularities did not usually appear to be very serious. After several months of outdoor exposure, a number of the panels showed visual evidence of deterioration.

Microscopic examinations were made to study the influence of exposure and other tests on the microscopic components of the materials. In some cases, microcracking of plastics was revealed, which could not be detected with the unaided eye.

Use of a medium-power objective with a metallographic microscope permitted viewing the beads in plastics and beads-on-paint in some detail. Scanning of the surface of a number of the materials revealed that clear, reflecting beads were nearly outnumbered by opaque, translucent or discolored nonreflecting beads.

Any relatively minor erosion, checking, filming, or other deterioration of the plastic overlying the beads was observed to reduce or mask their retroreflective quality. Damage or deterioration of the binder had the same effect of reducing the reflective quality.

Through examination at medium magnification, it was also noted that considerable blistering, some shrinkage and crystallizing of the plastics had occurred in many of the sign facings exposed in South Florida. This evidence of deterioration could not be seen with the unaided eye. A summary of microstructural and surface conditions of panels exposed to outdoor weathering at San Antonio for 5 to 7 months as examined by low-power microscopy follows:

Material No. 1

No damage was observed. There were a few loose and lost beads. The surface was slightly stained but essentially free of dirt.

Material No. 2

The surface was free of cracks; a few beads had been dislodged, and some dirt specks were distributed over the surface.

Material No. 3

Cracking had begun to develop in the red overlay. This was visible only with a microscope. The cracks appeared to have initiated at the bead-matrix interface.

Material No. 4

The only damage noted was dirt, and this was pronounced.

Material No. 8

There was no evidence of damage, and dirt specks were minimal.

Material No. 9

There were several abrasions and a moderate dirt accumulation.

Material No. 10

There was a noticeable concentration of surface dirt and dust and some shallow scratches.

Material No. 12

All of the beads had been lost, and the sheeting had peeled away from the plywood a distance of an inch from the edge of the panel.

Material No. 14

Microscopic cracks were seen in the matrix between the beads; dust and dirt accumulation on the surface was minimal.

Material No. 15

The sample was markedly dirtier than any others except No. 22. A few long microscopic cracks were visible. The cracks were in the matrix and did not originate at bead-matrix interface.

Material No. 22

This surface was characterized by an excessive accumulation of trash and dirt. There were some visible scratches.

Material No. 23

This surface was dirty. The distribution, disposition, concentration and character of the beads appeared to make dirt easily visible.

3. Accelerated Laboratory Tests

Some work was conducted during this project toward establishing a basis for the development of rapid or accelerated laboratory tests for evaluating sign-facing materials. Such tests would be useful for screening new materials and might make it possible to predict the probable use-life of materials. In view of this, while conducting routine laboratory tests and examinations on sign-facing materials, as described in other sections of this report, attention was given to possible modifications of existing methods and tests, or development of new ones. Several of these were used, such as for the determination of abrasion resistance, impact resistance, and the producing of "dew" conditions during reflectance tests. With some refinements, it is likely that these methods and tests can be used in predicting behavior patterns, performance, and use-life of materials.

A completely reliable accelerated weather-exposure test has not been developed. Accelerated weathering tests are performed to give answers in a reasonably short time on the possible or probable effects of long-time outdoor exposure of materials. Rapid, short-term tests generally will only indicate behavior trends rather than establish absolute behavior patterns. There are two general methods of producing rapid or accelerated weathering: 1) continuous exposure to simulated environments, and 2) the use of increased-intensity conditions.

The continuous-exposure method appears to be the least reliable. Primarily, it does not simulate the effects of intermittent, natural weathering cycles. In addition, there may not be sufficient time for the products of aging to form and exert their influence on materials under the continuous influence of water, heat and light.

The increased-intensity method is felt to simulate more closely the intermittent natural weathering process, though under more severe conditions. This method may produce results which might never occur at the lower natural intensity of outdoor exposure. Neither is there assurance that large increases in the intensity of various simulated conditions will cause a proportionate increase in deterioration. The short-cycle, high-intensity exposure may, and probably will, cause an exaggerated increase in the rate of material breakdown.

Since the normal, natural weathering cycle is generally a slow process subject to many unexpected variables, accelerated testing is performed by most of the plastics and paint manufacturers, users of these materials, etc. With care in interpretation of results, short-term weathering tests can be used to gain some reasonable indication of the expected performance of certain materials under certain conditions. The results must be used with full knowledge of how a particular type of material deteriorates and of all the factors that are important in causing degradation.

An attempt was made to combine natural weathering with an artificial condition such that a reasonably realistic accelerated deterioration would occur. Several samples of facing materials were mounted on plywood, and the panels were placed on the roof of one of the Institute's engine-testing laboratories. The samples were located approximately 20 feet from the main vent discharging from the upper part of the building; the exhaust air was drawn from the space over the engines. In addition to the main vent, a number of engine exhausts were located more than 20 feet from the panels. Figure 16 shows the results. In each case the panel to the left -- or the one that is white-appearing -- is the material in the new condition, while on the right is the panel after 30 days' exposure in the extreme environment. In the top row the panels in pairs are, from left to right: Materials Nos. 3, 4, and 15; in the bottom row the panels are, from left to right: Materials Nos. 5, 1, and 14.

The exposed panels were cleaned over the top two inches with simple detergent and water, while the bottom two inches were cleaned with trichlorothene.

After exposure and under daylight conditions, the various colors of the facing materials were reasonably identifiable. However, under night illumination the identities of the colors were barely discernible and, as can be seen in the photographs, the retroreflective qualities were almost completely lost. The exposed panels were examined for retroreflective brightness, but insufficient light was returned to be recorded on the apparatus in the light tunnel. It is admitted that this was a rather extreme test. It does indicate, though, that under the given environmental condition to which these were exposed, it may be possible to determine in a very short period of time something of the conditions which lead to failure of various types of facing materials.

4. Durability

a. Weatherability

Weatherability denotes the effects that exposure to service conditions have on materials' properties and/or performance. In the case of plastics and paints used in sign facing, weather can cause changes in properties by both physical and chemical means, such as:

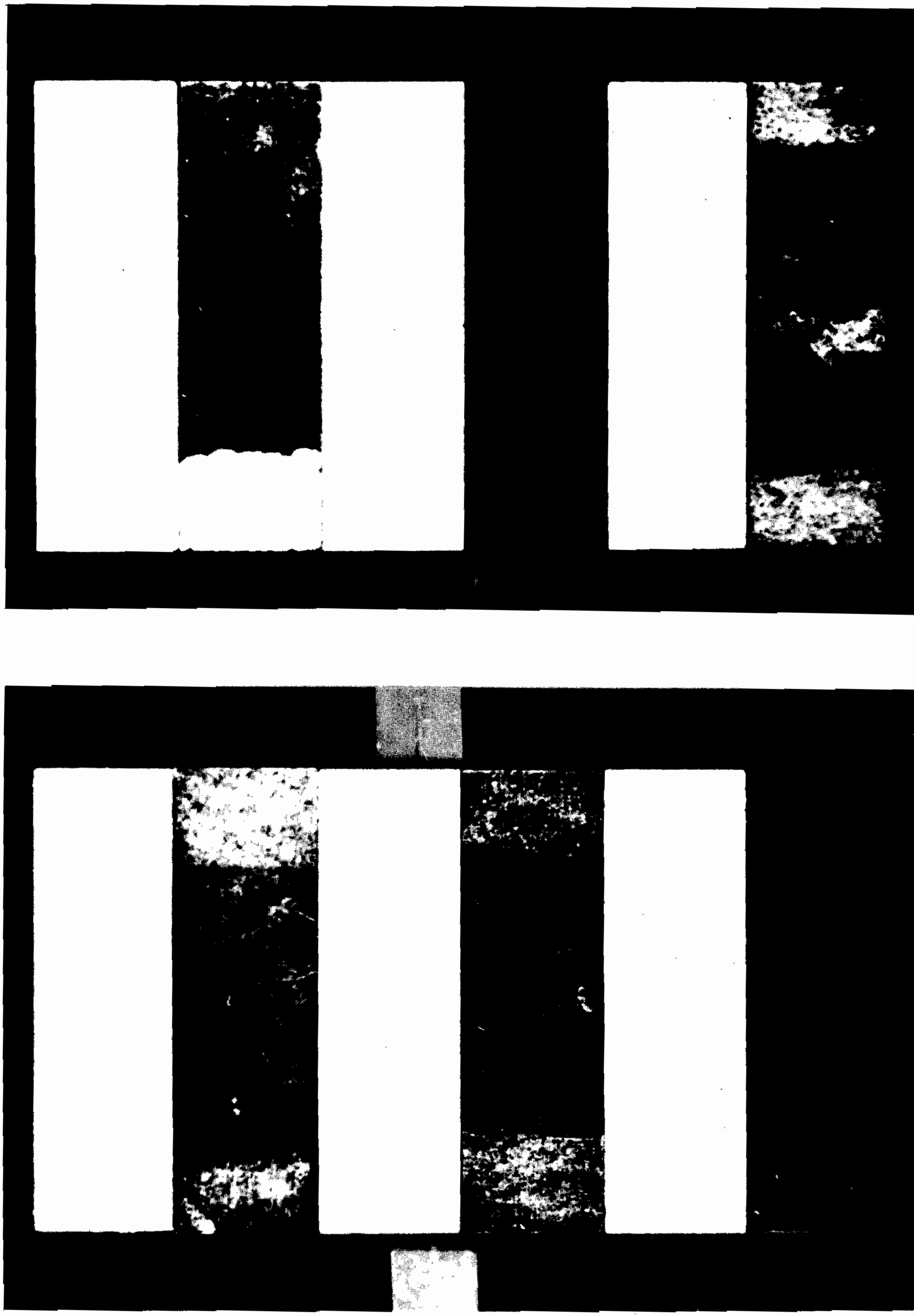


FIGURE 16. TEST PANELS AFTER EXTREME ENVIRONMENTAL EXPOSURE. As-new condition on left -- exposed on right.

1) Thermal reactions.

2) Radiation reactions (solar).

3) Chemical decomposition.

4) Volatilization of components.

5) Physical damage.

Most of these factors are interrelated in the various combinations and ways in which changes may be brought about.

Weather is due to variations in elements such as sunlight, rain, wind, oxygen (and ozone), temperature, humidity, and airborne impurities. The deterioration of sign-facing materials may be due to the effects of any one of these elements or, more likely, by a combination of them. It is the combined effects of weathering on materials which determine their suitability for service under a given set of outdoor conditions; the rate and severity of deterioration determine use-life.

Visible light has very little or no known effect on plastics and paint materials. It is the infrared at one end of the sunlight spectrum and ultraviolet at the other end that cause most reactions in organic materials. Considerable change and decomposition can be caused in these materials by ultraviolet radiation, which comprises only about 4% of the total sunlight reaching the earth. This decomposition effect is known as ultraviolet degradation, or photodegradation. Infrared radiation makes up about 53% of the total sunlight reaching earth. These rays are converted to heat as they strike the surface of a material and are absorbed by it, causing thermal reactions to take place in most plastics.

Oxygen in the air can combine with most materials and, particularly in the case of plastics, cause the material to break down or oxidize. Elevated temperatures generally cause an increase in the reaction rates.

Water can cause organic materials to swell or shrink and can leach out certain components of plastics. Under conditions of high humidity, this is particularly true. Freezing and thawing of moisture on a sign face may cause cracking and other damage. Hail may cause damage by impact. A common cause of damage to signs is that due to impact by missiles such as gravel, bottles, etc. If the sign facing is scuffed or torn, weather damage is accelerated due to the entrance of moisture into the opening.

Substances such as dust, sand, chemicals and others that are carried by the wind or are airborne can have destructive effects on sign facings. Deterioration can be due to abrasion, chemical reaction, growth of fungus, or the effects of rapid drying by the wind.

Some deterioration in the properties of sign facings is more or less temporary, as in the case where facings become dirty but can be cleaned to a reasonable extent.

Early in the study, it was believed that tendencies toward instability or degradation might be manifested during relatively short periods of outdoor exposure, such as from three to six months. Of particular interest was the difference in degrees of susceptibility of the various signing materials to the effects of relatively short-time outdoor exposure.

Samples of various sign-facing materials were applied to wood, aluminum, and steel test panels and placed at four outdoor stations for exposure. The locations were in South Florida, and in Texas at San Antonio, Sarita (South Texas), and Monahans (West Texas). In Texas, the panels were mounted on racks, as shown in Figure 17. At the South Florida station, the panels were mounted on commercial inland exposure racks.

San Antonio Exposure Panels. Fifty-two test panels were placed on exposure at San Antonio and were under close observation. The panels represented nineteen sign-facing materials of different colors and types. Twenty-one samples were mounted on high-density plywood, twelve were on aluminum backings, nine were on galvanized steel, and seven were mounted on special backing materials. The remaining three panels were backing material only, without facings; they were exposed in order to observe the effects of weathering on uncovered or untreated metals.

The total number of days on exposure was not the same for all materials, due primarily to availability of materials. All of the sign-facing materials were examined and their properties measured before the beginning of exposure. Three series of photometric readings were taken on these materials during and after exposure, and a final visual examination was made.

The data in Tables XII and XIII indicate the effects of weathering on the reflective intensity as measured in the photometric tunnel both before and after exposure, at divergence angles of 0.2 degree and 0.5 degree, respectively. Inspection of the data shows the wide range of values for similar materials. After exposure, some samples were brighter, but most showed a substantial decrease in brightness.

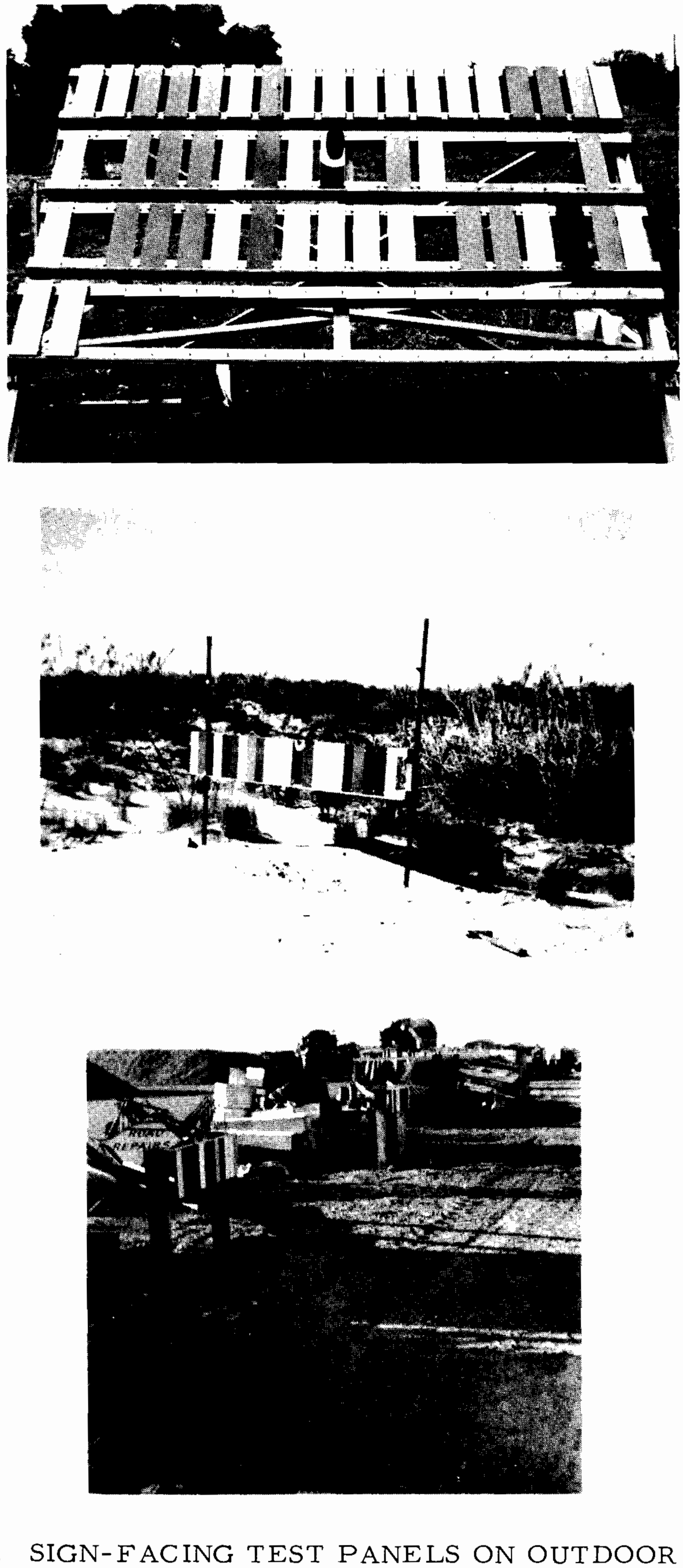


FIGURE 17. SIGN-FACING TEST PANELS ON OUTDOOR EXPOSURE RACKS LOCATED IN VARIOUS TEXAS AREAS.

TABLE XII. EFFECTS OF OUTDOOR EXPOSURE AT SAN ANTONIO, TEXAS ON REFLECTIVE INTENSITY FOR DIVERGENCE ANGLE OF 0.2 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1		2		3A		4		5		8		9		10	
	New	271*	New	271*	New	271	New	271	New	188	New	257	New	257	New	257
-4	15.4	4.8	17.0	8.5	12.6	5.0	13.4	6.0	240.0	168.0	55.0	50.0	5.9	2.5	11.0	3.3
0	15.4	4.8	17.0	8.5	26.5	18.3	18.4	7.8	240.0	180.0	187.0	100.0	39.6	20.0	67.5	19.0
5	15.4	4.8	17.0	8.0	11.9	4.5	13.4	5.0	240.0	194.0	47.5	37.5	5.8	2.0	10.0	2.8
10	15.3	4.8	16.7	7.8	11.6	4.5	12.7	4.5	215.0	205.0	33.0	19.3	4.8	1.6	7.0	2.0
15	14.8	4.5	15.7	7.5	11.0	4.0	11.0	4.0	190.0	205.0	15.6	6.3	2.2	1.0	3.6	1.3
20	14.3	4.5	14.5	6.8	9.5	4.3	9.7	3.5	162.0	194.0	5.6	1.7	1.2	0.6	1.4	0.9
30	12.6	3.8	9.5	3.5	5.5	2.0	5.3	2.0	90.0	105.0	0.6	0.4	0.2	0.4	0.3	0.4
40	10.7	3.0	6.9	2.8	1.6	0.8	2.1	1.1	42.5	33.0	0.1	0.3	0.07	0.5	0.08	0.3

Angle of Incidence, Degrees	14A		15A		15B		22		23	
	New	271*	New	271	New	231	New	231	New	115
-4	95.0	82.5	17.6	3.8	17.6	3.9	6.9	2.5	42.5	35.0
0	97.5	87.5	19.8	3.8	19.8	4.8	8.1	2.8	44.0	35.0
5	93.8	80.0	17.2	3.5	17.2	3.9	5.6	1.8	40.5	33.8
10	87.5	72.5	11.7	2.8	11.7	3.5	5.3	1.7	38.0	30.0
15	81.3	62.5	4.4	1.5	4.4	1.8	4.9	1.6	35.3	25.0
20	68.7	50.0	1.2	0.7	1.2	0.8	4.4	1.5	30.2	20.0
30	40.0	20.0	0.2	0.3	0.2	0.4	2.9	1.3	18.8	10.0
40	12.5	5.8	0.05	0.3	0.05	0.3	1.6	0.8	9.0	3.5

*Note: These numbers denote days of outdoor exposure facing south at 45 degrees.

TABLE XIII. EFFECTS OF OUTDOOR EXPOSURE AT SAN ANTONIO, TEXAS ON REFLECTIVE INTENSITY FOR DIVERGENCE ANGLE OF 0.5 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1		2		3A		4		5		8		9		10	
	New	271*	New	271*	New	271	New	271	New	188	New	257	New	257	New	257
-4	9.8	3.8	14.1	6.3	4.5	3.2	5.3	4.1	106.3	50.0	25.0	17.5	3.7	3.5	6.3	3.9
0	9.8	3.8	14.1	6.3	19.1	12.0	9.9	5.9	102.5	50.0	106.3	42.5	43.8	19.3	35.0	19.5
5	9.8	3.5	14.0	6.3	4.4	3.2	5.3	3.6	105.0	47.5	24.8	17.5	3.3	3.0	4.5	3.8
10	9.8	3.5	13.6	5.9	4.2	3.2	5.0	3.5	107.5	48.8	19.8	17.0	2.4	2.5	3.6	3.1
15	9.7	3.4	12.6	5.3	4.1	3.1	4.8	3.3	110.0	55.0	11.9	10.0	1.8	2.0	2.3	2.3
20	9.0	3.3	11.0	4.7	3.8	3.0	4.3	2.8	105.0	57.5	6.0	4.0	1.0	1.4	1.0	1.7
30	7.8	2.8	6.5	3.0	2.4	2.5	2.5	2.3	68.8	62.5	1.1	1.2	0.2	0.8	0.3	0.9
40	6.7	2.0	4.5	2.1	1.2	1.4	1.5	1.5	30.0	45.5	0.5	0.8	0.05	0.6	0.02	0.7

Angle of Incidence, Degrees	14A		15A		22		23	
	New	271*	New	271	New	231	New	115
-4	45.0	32.5	11.9	6.5	3.5	3.4	19.0	18.8
0	47.5	35.0	13.4	6.8	4.8	4.0	19.8	20.0
5	42.5	31.8	11.7	6.0	3.0	2.8	17.5	18.0
10	42.5	30.0	7.7	4.9	2.8	2.5	17.0	17.5
15	40.0	30.0	2.5	3.3	2.5	2.5	15.8	16.5
20	37.5	28.0	0.9	1.8	2.3	2.4	14.8	15.0
30	25.0	19.3	0.1	0.8	1.7	2.0	11.5	10.8
40	10.0	8.8	0.03	0.6	0.9	1.5	6.2	6.3

*Note: These numbers denote days of outdoor exposure facing south at 45 degrees.

Spectrophotometric data obtained on the exposure panels mentioned previously are contained in Tables XIV, XV, and XVI. As can be determined from the data, color changes occurred in many of the materials during the exposure period. However, these color changes were hardly discernible by either visual examination or comparison with unexposed material.

West Texas Exposure Panels. Twenty-two sign-facing test panels were placed on exposure racks at Monahans, Texas. One of the main purposes in exposing the panels in this West Texas area was to observe the abrasive effects of wind-blown sand. Photometric data were obtained on these panels before and after exposure.

The reflective intensity values of the facing materials as shown in Table XVII indicate the occurrence of some changes in brightness after only 112 days' exposure. The spectrophotometric data in Table XVIII, for the Monahans test panels, also indicate some changes in chromatic values due to exposure or sand abrasion. No information was readily available on the frequency or intensity of blowing sand during the exposure period. Thus, the data were insufficient to provide a basis for any valid conclusions as to abrasion due to wind-blown sand. Substantial changes in brightness values (Table XVII) may indicate deterioration by causes other than blowing sand.

South Texas Exposure Panels. Twenty-two sign-facing test panels were placed on outdoor exposure in the vicinity of Sarita, Texas. This location was chosen because of the prevailing damp coastal weather conditions and the occurrence of wind-borne sand. Exposure was for a period of 95 days, with the panels placed vertically and facing approximately southeast into the prevailing winds. Photometric data were obtained on these panels before and after exposure. Table XIX gives the reflective intensity data for comparison. As in the Monahans exposure test, the exposure conditions at Sarita in South Texas were about as severe as had been expected. The values in Table XIX indicate that a considerable change in brightness occurred during exposure. Spectrophotometric values, as shown in Table XX, indicate substantial changes in color values.

South Florida Exposure Panels. Date on weathering characteristics were obtained on sign-facing panels and several special backing materials after outdoor exposure in South Florida. Twenty-nine panels were placed on simple 45-degree, south-facing exposure on October 8, 1965, and were removed on May 8, 1966, for a total exposure period of seven months (212 days). During the seven-month period, the panels received a total of 28.41 inches of rainfall, from a minimum of 0.58 inch in December to a maximum of 11.45 inches in September. Total seven-month radiation by sunlight was 54,590 Langleys, based on a daily radiation level above 0.823 Langley.

TABLE XIV. EFFECTS OF OUTDOOR EXPOSURE AT SAN ANTONIO, TEXAS ON CIE CHROMATICITY COORDINATES, HIGH DENSITY PLYWOOD BACKING

Sample Code Number	Unexposed Chromaticity Coordinates			Exposure Time, Days	Chromaticity Coordinates			Exposure Time, Days	Chromaticity Coordinates		
	x	y	Y		x	y	Y		x	y	Y
1	0.324	0.333	76.38	91	0.321	0.332	70.27	271	0.319	0.332	60.71
2	0.314	0.329	84.05	57	0.318	0.328	74.43	271	0.320	0.333	69.86
3A	0.561	0.314	9.66	57	0.501	0.317	11.16	271	0.448	0.317	14.01
3B	0.561	0.314	9.66	47	0.492	0.319	10.87	231	0.432	0.370	15.81
4	0.197	0.414	12.74	90	0.257	0.419	13.03	271	0.246	0.374	15.44
5	0.315	0.318	50.49	--	--	--	--	188	0.328	0.334	45.67
8	0.323	0.340	46.66	57	0.318	0.329	48.40	257	0.318	0.331	50.25
9	0.530	0.333	10.83	57	0.496	0.332	13.60	257	0.451	0.331	16.18
10	0.215	0.394	16.19	76	0.210	0.363	17.07	257	0.241	0.308	19.84
11	0.253	0.368	16.60	90	0.253	0.354	17.17	271	0.264	0.349	19.14
12	0.311	0.316	74.69	85	0.314	0.324	71.13	265	Complete deterioration		
14A	0.321	0.344	58.89	91	0.231	0.298	59.53	271	0.316	0.338	57.73
14B	0.321	0.344	58.89	51	0.264	0.286	56.01	231	0.320	0.338	55.61
15A	0.229	0.384	16.91	91	0.241	0.381	16.98	271	0.263	0.361	19.20
15B	0.229	0.384	16.91	51	0.233	0.368	17.44	231	0.248	0.370	19.48
17	0.232	0.363	15.72	85	0.242	0.386	17.68	265	0.253	0.351	19.28
22	0.213	0.199	6.14	50	0.430	0.172	8.24	231	0.236	0.233	10.81
23	0.486	0.446	37.94	50	0.477	0.439	36.77	231	0.454	0.427	38.33
24	0.488	0.348	26.09	50	0.479	0.355	27.71	231	0.436	0.361	35.91

TABLE XV. EFFECTS OF OUTDOOR EXPOSURE AT SAN ANTONIO, TEXAS ON CIE CHROMATICITY COORDINATES, ALUMINUM BACKING

Sample Code Number	Unexposed Chromaticity Coordinates			Exposure Time, Days	Chromaticity Coordinates			Exposure Time, Days	Chromaticity Coordinates		
	x	y	Y		x	y	Y		x	y	Y
1	0.324	0.333	76.38	82	0.323	0.325	69.51	264	0.315	0.327	59.69
3A	0.561	0.314	9.66	82	0.492	0.335	12.03	264	0.465	0.332	13.83
3B	0.561	0.314	9.66	50	0.495	0.319	11.32	231	0.436	0.322	12.42
4	0.197	0.414	12.74	82	0.225	0.375	13.54	264	0.244	0.363	15.67
5	0.306	0.320	53.79	7	0.316	0.325	58.10	188	0.316	0.324	54.05
6	0.482	0.338	13.53	9	0.440	0.442	12.82	190	0.486	0.302	14.04
8	0.323	0.340	46.66	76	0.402	0.286	46.12	257	0.303	0.334	47.88
11	0.252	0.368	16.60	82	0.215	0.301	17.51	264	0.257	0.349	19.03
12	0.311	0.316	74.69	82	0.346	0.255	51.05	264	Completely deteriorated		
14	0.321	0.344	58.89	51	0.341	0.372	57.44	231	0.322	0.341	55.32
17	--	--	--	--	--	--	--	264	0.253	0.354	19.36
22	0.213	0.199	6.14	50	0.207	0.248	9.15	231	0.244	0.234	10.10

TABLE XVI EFFECTS OF OUTDOOR EXPOSURE AT SAN ANTONIO, TEXAS ON CIE CHROMATICITY COORDINATES, GALVANIZED STEEL BACKING

Sample Code Number	Unexposed Chromaticity Coordinates			Exposure Time, Days	Chromaticity Coordinates			Exposure Time, Days	Chromaticity Coordinates		
	x	y	Y		x	y	Y		x	y	Y
1	0.324	0.333	76.38	82	0.307	0.334	69.76	264	0.320	0.325	60.50
3A	0.561	0.314	9.66	51	0.489	0.332	12.38	231	0.422	0.328	13.59
4	0.197	0.414	12.74	82	0.298	0.547	12.99	264	0.249	0.363	15.38
5	0.325	0.327	63.54	--	--	--	--	188	0.318	0.324	54.48
8	0.323	0.340	46.66	76	0.313	0.326	50.26	257	0.318	0.329	51.60
14A	0.321	0.344	58.89	51	0.322	0.343	57.74	231	0.318	0.339	55.88
22	0.213	0.199	6.14	51	0.226	0.221	8.29	231	0.240	0.244	10.97
29	0.434	0.314	11.28	--	--	--	--	187	0.462	0.299	13.57

TABLE XVII. EFFECTS OF OUTDOOR EXPOSURE AT MONAHANS, TEXAS ON REFLECTIVE INTENSITY FOR DIVERGENCE ANGLE OF 0.2 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1		3		4		5		6		8		9		10	
	New	112*	New	112*	New	112	New	112	New	112	New	112	New	112	New	112
-4	15.4	1.5	12.6	2.0	13.4	4.5	240.0	137.0	5.2	0.9	55.0	15.8	5.9	1.3	11.0	2.3
0	15.4	1.6	26.5	8.0	18.4	5.0	240.0	137.0	5.2	1.0	187.0	35.0	39.6	11.3	67.5	11.3
5	15.4	1.5	11.9	2.0	13.4	3.8	240.0	137.0	5.6	0.9	47.5	13.8	5.8	1.0	10.0	1.8
10	15.3	1.5	11.6	2.0	12.7	3.5	215.0	125.0	5.6	0.9	33.0	6.3	4.8	0.9	7.0	1.3
15	14.8	1.5	11.0	1.9	11.0	3.3	190.0	100.0	6.0	0.9	15.6	2.8	2.2	0.7	3.6	0.8
20	14.3	1.4	9.5	1.7	9.7	2.8	162.0	19.8	6.0	0.9	5.6	2.3	1.2	0.6	1.4	0.5
30	12.6	1.2	5.5	1.0	5.3	1.8	90.0	23.8	4.5	0.8	0.6	0.4	0.2	0.4	0.3	0.4
40	10.7	1.0	1.6	0.6	2.1	1.1	42.5	8.8	2.9	0.6	0.1	0.4	0.07	0.4	0.08	0.4

Angle of Incidence, Degrees	14		15		22	
	New	112*	New	112	New	112
-4	95.0	40.0	17.6	3.0	6.9	1.9
0	97.5	42.5	19.8	3.0	8.1	2.5
5	93.8	40.0	17.2	2.8	5.6	1.6
10	87.5	40.0	11.7	1.9	5.3	1.5
15	81.3	27.5	4.4	1.0	4.9	1.4
20	68.7	25.0	1.2	0.5	4.4	1.3
30	40.0	10.0	0.2	0.4	2.9	0.9
40	12.5	2.5	0.05	0.4	1.6	0.6

*Note: These numbers denote days of outdoor exposure facing west at 90 degrees.

TABLE XVIII

SPECTROPHOTOMETRIC DATA ON MATERIALS EXPOSED AT MONAHANS, TEXAS

Material Code Nos.	CIE Color Coordinates					
	Unexposed As-Received			Exposed 112 Days		
	x	y	Y	x	y	Y
1B1	0.324	0.333	76.38	0.319	0.329	76.06
1B2	0.324	0.333	76.38	0.318	0.328	76.86
2B1	0.314	0.330	84.05	0.314	0.325	81.35
3B1	0.561	0.315	9.66	0.425	0.321	17.68
3B2	0.561	0.315	9.66	0.427	0.318	17.93
4B1	0.197	0.414	12.74	0.255	0.350	19.42
4B2	0.197	0.414	12.74	0.256	0.346	19.11
5B1	0.306	0.320	53.79	0.324	0.327	51.26
5B2	0.306	0.320	53.79	0.313	0.323	60.33
6B2	0.482	0.330	13.48	0.401	0.325	19.19
8B1	0.323	0.340	46.66	0.313	0.325	55.09
8B2	0.323	0.340	46.66	0.316	0.338	51.97
9B1	0.530	0.334	10.83	0.420	0.326	19.62
10B1	0.215	0.394	16.19	0.242	0.353	22.89
11B1	0.252	0.368	16.60	0.266	0.343	23.17
11B2	0.252	0.368	16.60	0.267	0.343	23.32
12B1	0.314	0.316	74.69	0.316	0.327	73.63
12B2	0.314	0.316	74.69	0.316	0.327	72.04
14B1	0.321	0.344	58.89	0.318	0.333	62.12
15B1	0.230	0.384	16.91	0.231	0.365	23.41
19B7	0.270	0.338	20.24	0.262	0.338	20.30
22B2	0.213	0.199	6.14	0.259	0.265	13.85

TABLE XIX. EFFECT OF OUTDOOR EXPOSURE AT SARITA, TEXAS ON REFLECTIVE INTENSITY FOR DIVERGENCE ANGLE OF 0.2 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1		3		4		5		6		8		9		10	
	New	95*	New	95*	New	95	New	95	New	95	New	95	New	95	New	95
-4	15.4	2.5	12.6	2.5	13.8	4.8	240.0	100.0	5.2	3.8	55.0	15.0	5.9	2.8	11.0	2.8
0	15.4	2.0	26.5	12.5	18.4	6.8	240.0	100.0	5.2	4.0	187.0	70.0	39.6	11.5	67.5	10.0
5	15.4	1.6	11.9	2.5	13.4	4.5	240.0	92.5	5.6	3.8	47.5	12.5	5.8	2.4	10.0	2.3
10	15.3	1.8	11.6	2.3	12.7	4.0	215.0	87.5	5.6	3.5	33.0	8.8	4.8	1.5	7.0	1.8
15	14.8	1.9	11.0	2.0	11.0	3.5	190.0	85.0	6.0	3.0	15.6	3.5	2.2	0.7	3.6	1.1
20	14.3	1.9	9.5	1.8	9.7	3.0	162.0	80.0	6.0	2.3	5.6	1.6	1.2	0.5	1.4	0.8
30	12.6	1.9	5.5	0.9	5.3	1.5	90.0	75.0	4.5	1.1	0.6	0.6	0.2	0.4	0.3	0.6
40	10.7	1.6	1.6	0.0	2.1	0.6	43.0	65.0	2.9	0.8	0.1	0.5	0.07	0.4	0.08	0.5

Angle of Incidence, Degrees	14		15		22		23	
	New	95*	New	95	New	95	New	95
-4	95.0	42.5	17.6	4.3	6.9	2.8	42.5	14.0
0	97.5	42.5	19.8	4.5	8.1	3.5	44.0	15.0
5	93.8	40.0	17.2	3.8	5.6	2.5	40.5	13.8
10	87.5	37.5	11.7	2.8	5.3	2.3	38.0	12.8
15	81.3	32.5	4.4	1.6	4.9	2.0	35.3	11.3
20	68.7	27.5	1.2	1.0	4.4	1.8	30.2	9.0
30	40.0	11.3	0.2	0.8	2.9	1.2	18.8	5.3
40	12.5	3.0	0.05	0.8	1.6	0.9	9.0	2.5

*Note: These numbers denote days of outdoor exposure facing southeast at 90 degrees.

TABLE XX

SPECTROPHOTOMETRIC DATA ON MATERIALS EXPOSED AT SARITA, TEXAS

Material Code Nos.	CIE Color Coordinates					
	Unexposed As-Received			Exposed 95 Days		
	x	y	Y	x	y	Y
1B1	0.324	0.333	76.38	0.317	0.327	75.05
1B2	0.324	0.333	76.38	0.316	0.329	77.42
3B1	0.561	0.315	9.66	0.435	0.325	17.25
3B2	0.561	0.315	9.66	0.494	0.377	17.07
4B1	0.197	0.414	12.74	0.254	0.354	18.73
4B2	0.197	0.414	12.74	0.279	0.295	14.17
5B1	0.306	0.320	53.79	0.327	0.336	51.69
6B2	0.482	0.330	13.48	0.416	0.325	18.56
8B1	0.323	0.340	46.66	0.345	0.307	49.69
8B2	0.323	0.340	46.66	0.312	0.326	50.56
9B1	0.530	0.334	10.83	0.433	0.328	19.79
10B1	0.215	0.394	16.19	0.329	0.360	22.81
11B1	0.252	0.368	16.60	0.301	0.327	21.83
11B2	0.252	0.368	16.60	0.263	0.345	21.96
12B1	0.314	0.316	74.69	0.313	0.324	74.31
12B2	0.314	0.316	74.69	0.311	0.324	74.42
14B1	0.321	0.344	58.89	0.318	0.338	60.39
15B1	0.230	0.384	16.91	0.257	0.353	22.16
19B7	0.270	0.338	20.24	0.263	0.335	19.07
22B2	0.213	0.199	6.14	0.247	0.254	13.05
23B2	0.486	0.447	37.94	0.443	0.418	41.57
26B1	0.497	0.424	27.96	0.418	0.430	41.95

The threshold of ultraviolet activity is accepted as 0.823 gram calories per square centimeter per minute (0.823 Langley). The mean daily relative humidity over the 212-day period was 68.1%, with day-to-day values ranging from a low maximum relative humidity of 73% on only two days to a high minimum of 93% on one day. Average maximum/minimum relative humidity was 60%. The average air-shade temperature was 68° F, and the mean daily temperature was 72.1° F.

Results of microscopic examination and physical evaluation of these panels are shown in Table XXI. It is apparent that a wide range of effects can be attributed to weathering, depending on the type of material. Similar materials behaved essentially the same except for color change. Of particular interest was the difference in degrees of susceptibility to the accumulation of dirt on the surface of the various sign-facing materials. Some of the flat-surface materials collected surface dirt more readily than open-face materials. A feature observed in some flat-surface sheeting was a tendence of the overcoat to become scratched or scuffed.

The effects on reflective intensity of outdoor exposure at the South Florida location are indicated by the data in Table XXII. The exposed panels were run in the photometric tunnel in the as-received condition, with no cleaning or washing done prior to measuring reflectance. After seven months' exposure, all of the test panels had reflective intensity values that were much less than those measured before exposure.

Table XXIII gives the spectrophotometric values for the South Florida exposure panels and indicates the effects on color of outdoor exposure under semitropical conditions. Generally, marked changes were observed in CIE coordinates and in reflective intensity values. The white and silver-white materials were found to have darkened and also decreased in the Y factor. The red colors faded to some extent, increased in the value of Y, and lost considerable reflectivity. The chromaticity coordinates, x and y, showed that the red colors also had changed to a purplish-red; visual observation was in agreement with this color shift. The green-colored materials showed no visible color changes; however, the photometric data indicate a slight but definite fading, with a color shift, and loss of reflective intensity.

b. Influence of Wet and "Dew" Conditions

Exposed and unexposed sign-facing materials were examined as recommended in Federal Specification LS-300 for retroreflective brightness when wet, and by a modification of this test for "dew" conditions. The wet test simulating rain may be described as "flooding" the facing materials, while the "dew" was similar to actual moisture condensation from fog or dew conditions. The results obtained are given in Table XXIV.

TABLE XXI. EXAMINATION AND PHYSICAL EVALUATION OF TEST PANELS EXPOSED AT FLORIDA LOCATION AFTER SEVEN MONTHS OUTDOOR EXPOSURE

Code and Backing		Observations
1B1	-	Fair condition. Soft, oily, bituminous-like specks distributed over surface. Slight yellowing of paint. Considerable erosion of beads.
1B2	-	Same as 1B1.
1B3	-	About the same as 1B1 but less dirt accumulation, and beads are more firmly bonded.
2B1	-	Fair condition. Black, oily dirt accumulation. Some softening of binder and adhesive. Beads well-bonded.
3B1	-	Good condition. Slight dirt accumulation but easily washed off. Very little abrasion. Slight softening of plastic and separation of beads from plastic.
3B2	-	Same as 3B1.
4B1	-	Same as 3B1.
4B2	-	Same as 3B1.
4B3	-	Same as 3B1.
4B4	-	Fair condition. About same as 3B1 except that lifting of sheeting edges has been caused by rust forming at edges of steel panel where aluminum coating has broken down.
14B1	-	Good condition. About same as 3B1.
15B1	-	Good to very good condition. Slight dirt accumulation. Minor softening of adhesive, apparently caused by adhesive activator solvent.
8B1	-	Fair condition. Color has lightened. Top layer soft and adhesion fair to poor. Dirt easily washed off. There are a number of areas showing a definite crystallization of the plastic in the bead layer.
8B2	-	Fair condition. Same as 8B1 but better adhesion.
8B3	-	Good condition except for faded color.
8B4	-	Fair to poor condition. Same as 8B1, except for severe rust-staining at edges.
8B5	-	Fair condition. Same as 8B1 except for some minor rust spots under adhesive.
8B6	-	Fair to good condition. Adhesion good. Color fading more severe than 8B1.
9B1	-	Fair condition. Slight color change. Adhesion poor, in general.
10B1	-	Fair condition. Several small areas have poor adhesion.
11B1	-	Excellent condition. No apparent changes in color, surface, and adhesion.
11B2	-	Excellent condition. Same as 11B1.
12B1	-	Failed. Beads entirely gone.
12B2	-	Failed. Beads gone.

TABLE XXI. (Cont d)

Code and Backing		Observations
17B1	-	Good condition. Adhesion fair. No color change.
17B2	-	Same as 17B1.
19B7	-	Excellent condition. No apparent changes in color, surface, and adhesion.
16B5	-	Special steel backing only. Material is in various stages of oxidation.
21B4	-	Aluminized steel backing only. Material is in good condition except for rusting at edges.

Notes on Backing Materials:

B1	-	High-density plywood as supplied to Texas Highway Department. All of the plywood panels showed evidence of considerable degradation in the form of cracking, splitting, mildew; and several had begun to rot.
B2	-	Aluminum as specified by Texas Highway Department. All of the aluminum panels were in very good condition.
B3	-	Steel as specified by Texas Highway Department. Most of the steel panels were in good condition. A few had some slight corrosion of zinc coating.
B4 & B5	-	See 16B5 and 21B4 above.
B6	-	Thin galvanized steel has some evidence of crazing in small areas along edges.
B7	-	Experimental coating of base treatment has powdered slightly where exposed.

TABLE XXII. EFFECT OF OUTDOOR EXPOSURE AT SOUTH FLORIDA LOCATION ON REFLECTIVE INTENSITY FOR DIVERGENCE ANGLE OF 0.2 DEGREE

Angle of Incidence, Degrees	Reflective Intensity and Respective Code Numbers															
	1		2		3		4		8		9		10		14	
	New	7*	New	7*	New	7	New	7	New	7	New	7	New	7	New	7
-4	15.4	3.0	17.0	4.8	12.6	3.0	13.4	4.8	55.0	32.5	5.9	0.8	11.0	1.5	95.0	35.0
0	15.4	2.8	17.0	4.8	26.5	11.3	18.4	6.3	187.0	52.5	39.6	7.5	67.5	13.8	97.5	38.7
5	15.4	3.0	17.0	4.5	11.9	2.8	13.4	4.3	47.5	27.5	5.8	0.4	10.0	1.1	93.8	35.0
10	15.3	3.0	16.7	4.3	11.6	2.5	12.7	4.0	33.0	14.5	4.8	0.0	7.0	0.7	87.5	32.5
15	14.8	3.0	15.7	4.0	11.0	2.4	11.0	3.5	15.6	4.3	2.2	--	3.6	0.0	81.3	30.0
20	14.3	3.0	14.5	3.5	9.5	2.1	9.7	2.8	5.6	1.0	1.2	--	1.4	--	68.7	23.8
30	12.6	2.8	9.5	1.9	5.5	1.2	5.3	1.6	0.6	0.0	0.2	--	0.3	--	40.0	11.0
40	10.7	2.1	6.9	1.3	1.6	0.4	2.1	0.7	0.09	0.0	0.07	--	0.08	--	12.5	2.0
-4	RT	0.4	RT	0.4	RT	2.5	RT	3.0	RT	35.0	RT	1.0	RT	1.3	RT	57.5

Angle of Incidence, Degrees	15	
	New	7*
-4	17.6	2.3
0	19.8	2.4
5	17.2	2.0
10	11.7	1.6
15	4.4	0.6
20	1.2	0.0
30	0.2	--
40	0.05	--
-4	RT	0.3

*Note: These numbers denote months of outdoor exposure facing south at 45 degrees.

RT – Rainfall Test on panels after exposure measured at incidence angle of -4 degrees.

TABLE XXIII

EFFECTS OF OUTDOOR EXPOSURE ON COLOR
45-Degree South-Facing at South Florida Station

Sample Code No.	Unexposed Chromaticity Coordinates Y	x	y	Exposure Time (Months)	Exposed Chromaticity Coordinates Y	x	y
Plywood Backing							
1	76.38	0.324	0.333	7	51.03	0.318	0.326
2	84.05	0.314	0.330	7	70.08	0.311	0.330
3	9.66	0.561	0.315	7	11.20	0.507	0.332
4	12.74	0.197	0.414	7	12.64	0.241	0.382
8	46.66	0.323	0.340	7	44.22	0.321	0.329
9	10.83	0.530	0.334	7	12.40	0.522	0.362
10	16.19	0.215	0.394	7	15.87	0.222	0.373
11	16.60	0.252	0.368	7	16.95	0.252	0.369
14	58.89	0.321	0.344	7	53.07	0.321	0.340
15	16.91	0.230	0.384	7	16.53	0.297	0.459
17	15.72	0.233	0.363	7	16.82	0.249	0.369
Aluminum Backing							
1	76.38	0.324	0.333	7	61.06	0.319	0.330
3	9.66	0.561	0.315	7	10.85	0.510	0.323
4	12.74	0.197	0.414	7	12.20	0.241	0.374
8	46.66	0.323	0.340	7	44.50	0.316	0.327
11	16.60	0.252	0.368	7	17.51	0.274	0.358
17	15.72	0.233	0.363	7	16.89	0.253	0.366
Steel Backing							
1	76.38	0.324	0.333	7	66.61	0.318	0.328
4	12.74	0.197	0.414	7	12.60	0.240	0.379
8	46.66	0.323	0.340	7	46.54	0.322	0.336

TABLE XXIV. REFLECTIVE INTENSITY VALUES OF EXPOSED AND UNEXPOSED SIGN-FACING MATERIALS AS INFLUENCED BY WET AND DRY CONDITIONS

Material Code	Exposure Time (Months)	Reflective Intensity Values: Unexposed Dry	Unexposed Flooded	Unexposed "Dew"	Exposed Dry	Exposed Flooded	Exposed "Dew"
1	7	21.0	1.4	2.0	3.9	0.7	*
2	7	24.0	1.3	1.5	6.1	0.7	*
3	7	12.7	12.7	9.8	3.9	3.3	*
4	7	17.5	1.7	*	6.1	0.6	*
9	7	7.8	7.2	2.0	1.3	1.4	*
10	7	16.3	15.3	13.8	2.0	1.7	1.3
14	7	95.0	95.0	44.0	37.0	57.0	22.0
15	7	20.0	0.8	1.3	3.0	0.2	*
29	0	1.9	0.5	0.6	Not run		
31	0	170.0	29.5	25.3	Not run		
32	0	6.6	0.3	0.8	Not run		

*Value below minimum on instrument scale.

Note: Divergence Angle 0.2 degree; Incidence Angle -4 degrees.

The "dew" condition appeared to have a more detrimental effect on brightness or reflectivity than did flooding the samples.

c. Spectrophotometer Data from Exposure Panels

Data from a number of studies of reflective sign-facing materials, taken both before and after exposure at several locations, were reduced by computation. Values of Y, the relative daylight reflectance or brightness, and wavelength in Angstrom units were then plotted on graphs. Figures 18 through 24 are graphs obtained for the various sign facings and colors - silver-white sheeting, white exposed-lens, white beads-on-paint, red, yellow, green, and blue, respectively. These curves not only illustrate the changes in reflectance caused by weathering, but also show the variation in color absorption (or reflectance) in the visible spectrum.

The importance of the spectrophotometer data and curves drawn from them lies largely in the general behavior patterns shown and in the wide range of degrees of stability of color parameters among the various materials. Generally, it was common for the brightness factor, Y, to increase during the initial stages of weathering. The reasons for this apparently are different for different types of facing materials. Some materials, such as Material No. 1, became brighter in color because of initial bleaching of the white pigment. In other materials, the increase in brightness is actually an increase in "whiteness" due to color fading or to the formation of a diffuse film on the surface. In both cases, the result directly influences the reflective intensity or retroreflective quality of the material. Changes in the spectral quality, whether major or minor as measured by instrument, were usually not of sufficient magnitude to be noticed by visual comparison.

5. Sign Examination and Monitoring

a. Field Monitoring

Field examinations were made during trips and on a systematic basis in a selected area for the purpose of securing a better understanding of environmental hazards to which highway signs are subjected and the damage that they receive. Numerous signs of varying types and sizes on segments of Interstate Highways were examined in this work. Since close inspection of facings was not practical, the emphasis was placed on obvious damage that was visible from a minimum distance of three to four feet. Deterioration and damage due to several causes are shown in Figure 25.

Results of periodic observations made on a group of signs in the San Antonio area were recorded and a log kept of sign conditions

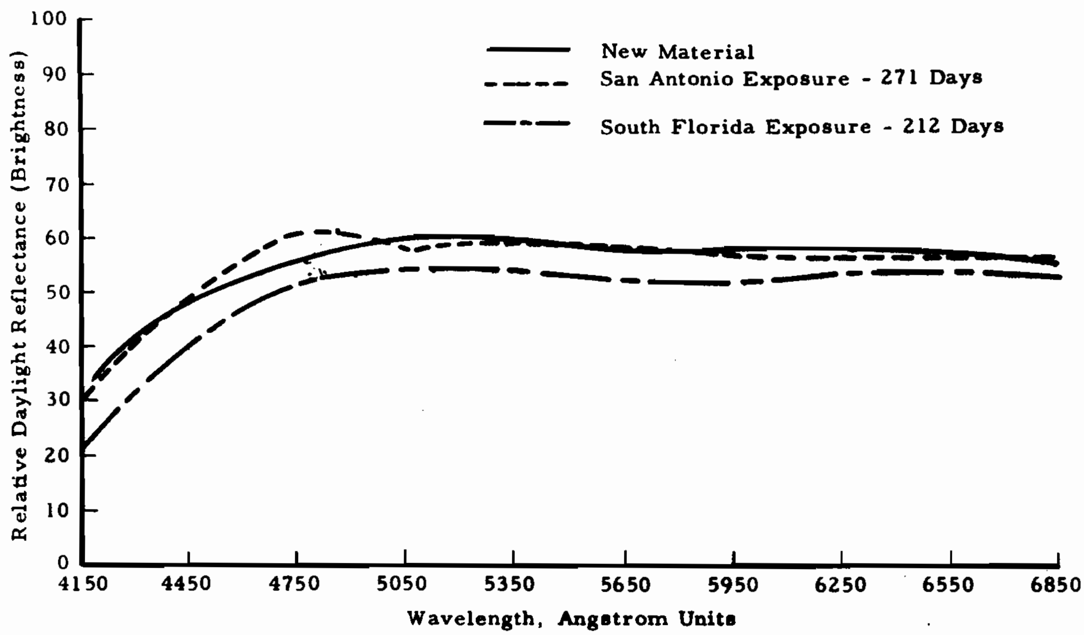


FIGURE 18. SPECTROPHOTOMETER CURVES OF SILVER-WHITE FLAT-SURFACE TYPE REFLECTIVE SHEETING SHOWING EFFECT OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

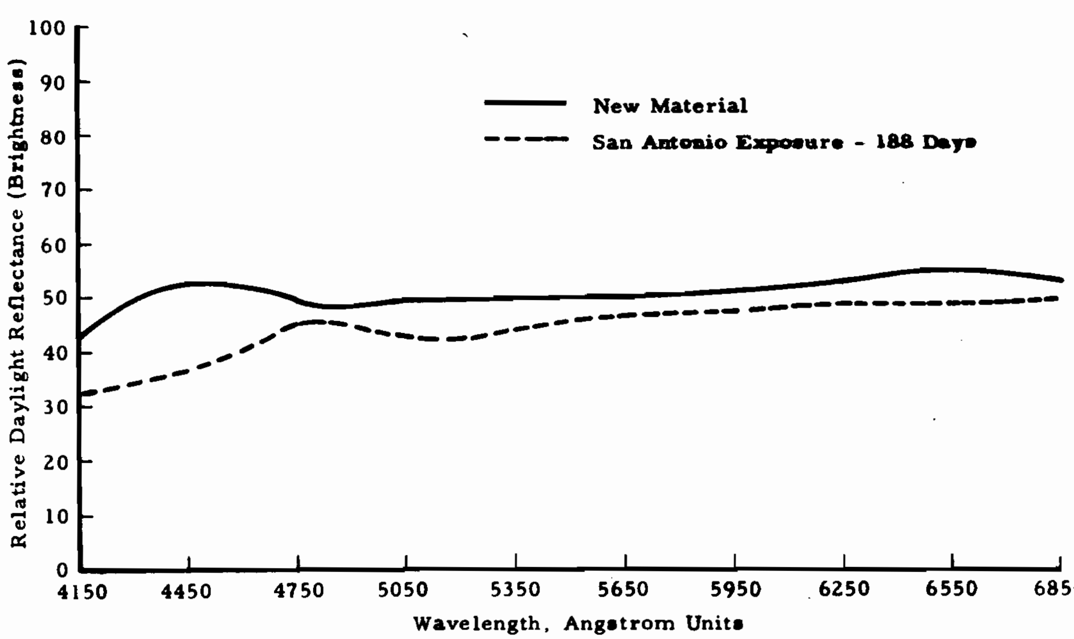


FIGURE 19. SPECTROPHOTOMETER CURVES OF WHITE EXPOSED-LENS TYPE REFLECTIVE SIGN-FACING MATERIAL SHOWING EFFECT OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

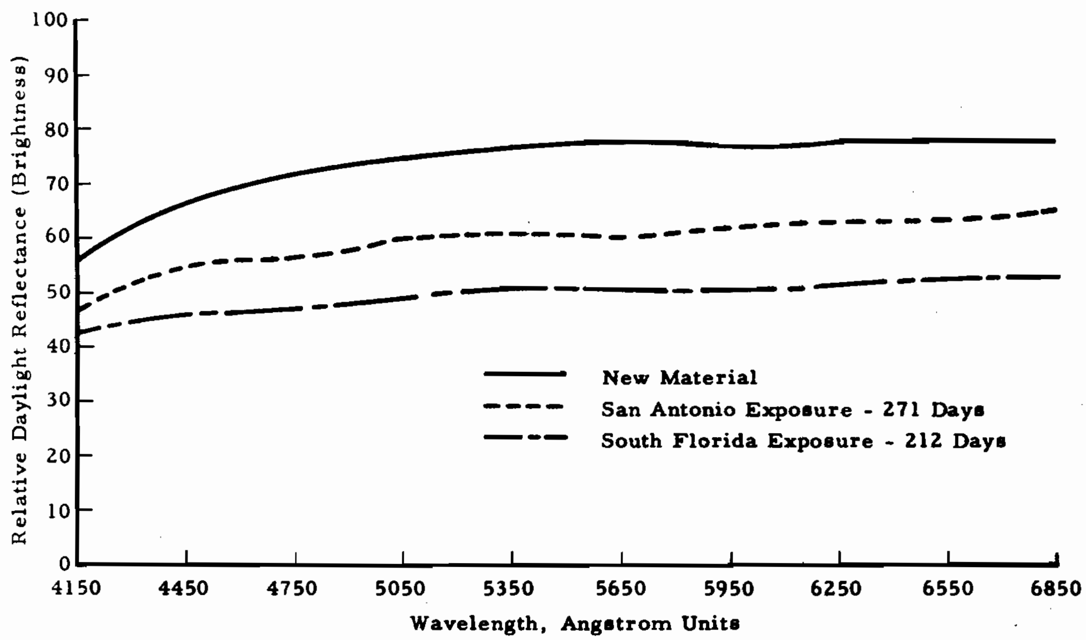


FIGURE 20. SPECTROPHOTOMETER CURVES OF WHITE BEADS-ON-PAINT TYPE REFLECTIVE SIGN-FACING MATERIAL SHOWING EFFECT OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

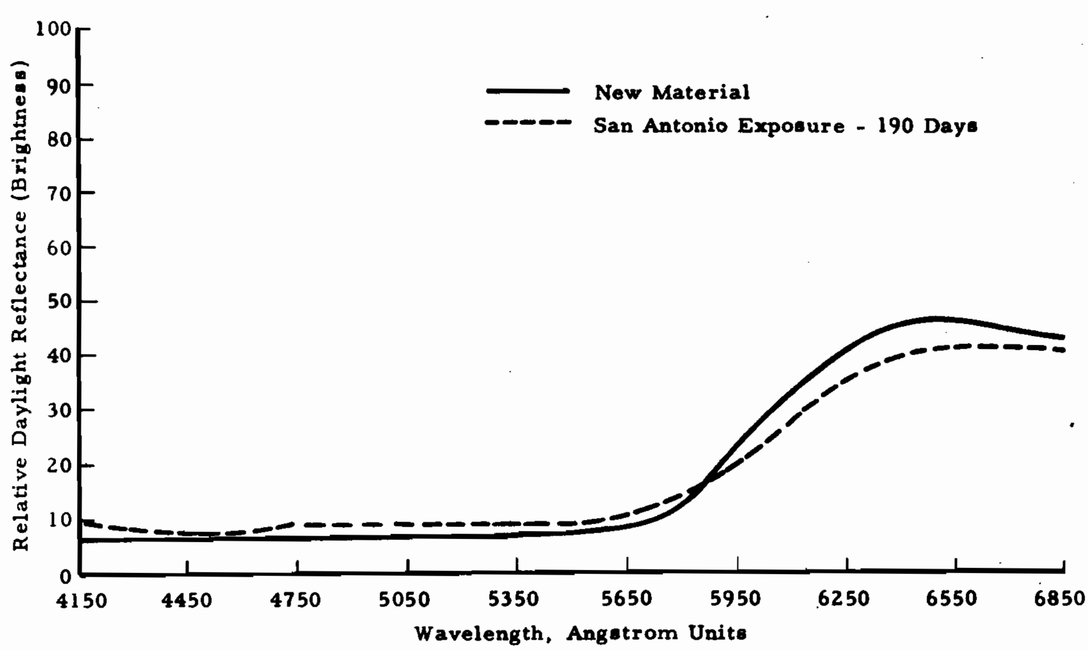


FIGURE 21. SPECTROPHOTOMETER CURVES OF TYPICAL RED REFLECTIVE SIGN-FACING MATERIAL SHOWING EFFECT OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

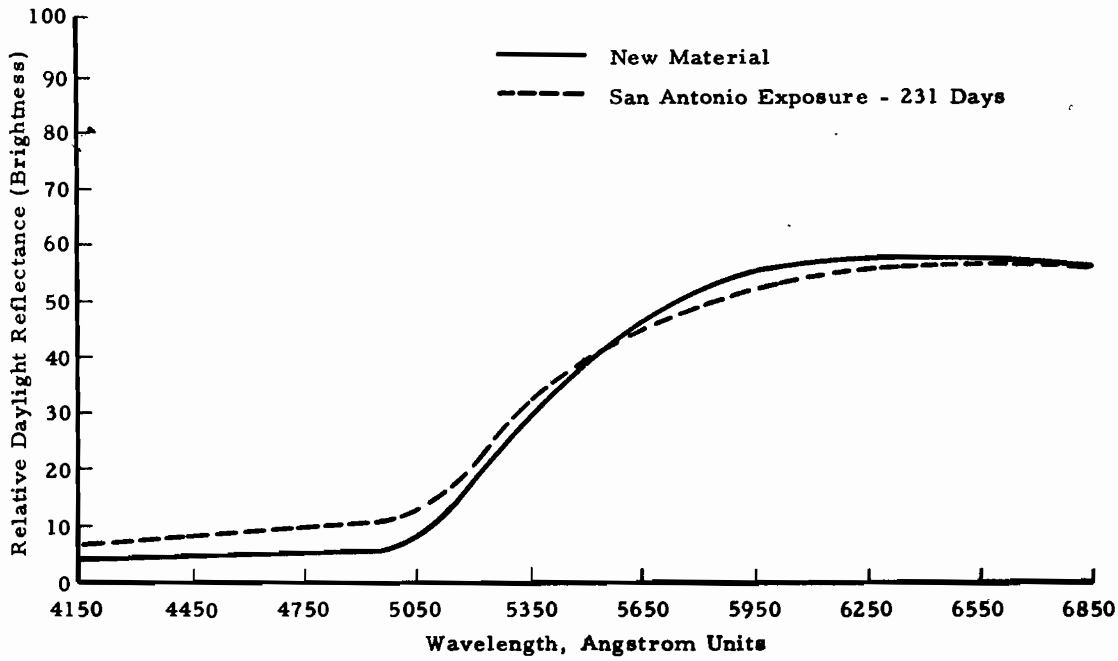


FIGURE 22. SPECTROPHOTOMETER CURVES OF YELLOW REFLECTIVE SIGN-FACING MATERIAL SHOWING EFFECT OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

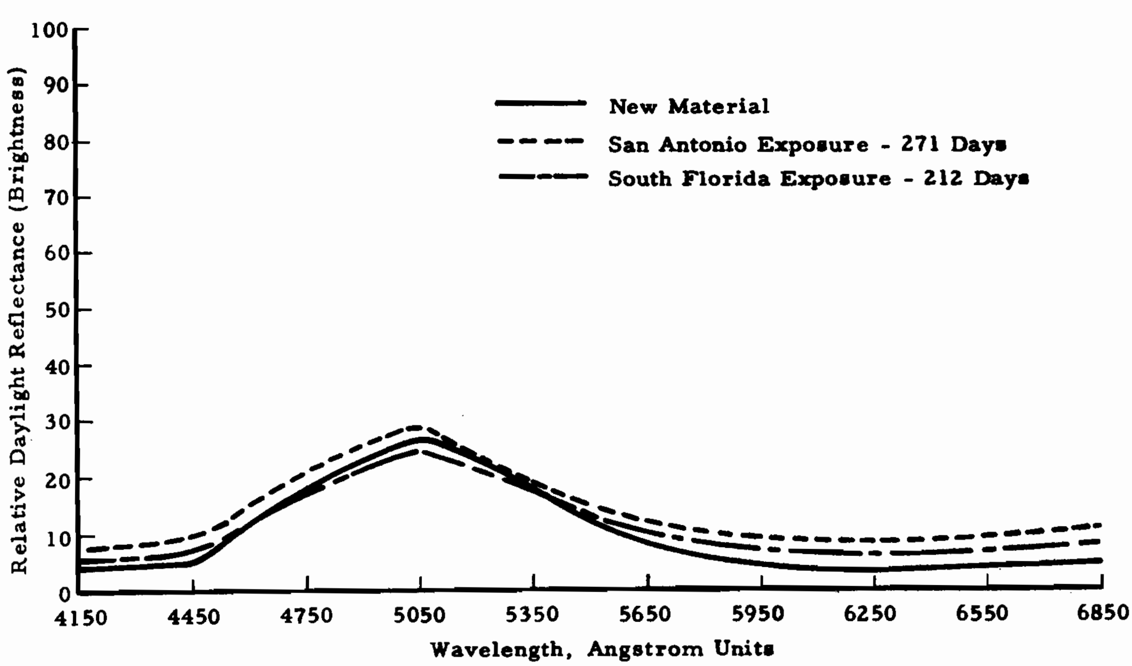


FIGURE 23. SPECTROPHOTOMETER CURVES OF GREEN REFLECTIVE SIGN-FACING MATERIAL SHOWING EFFECT OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

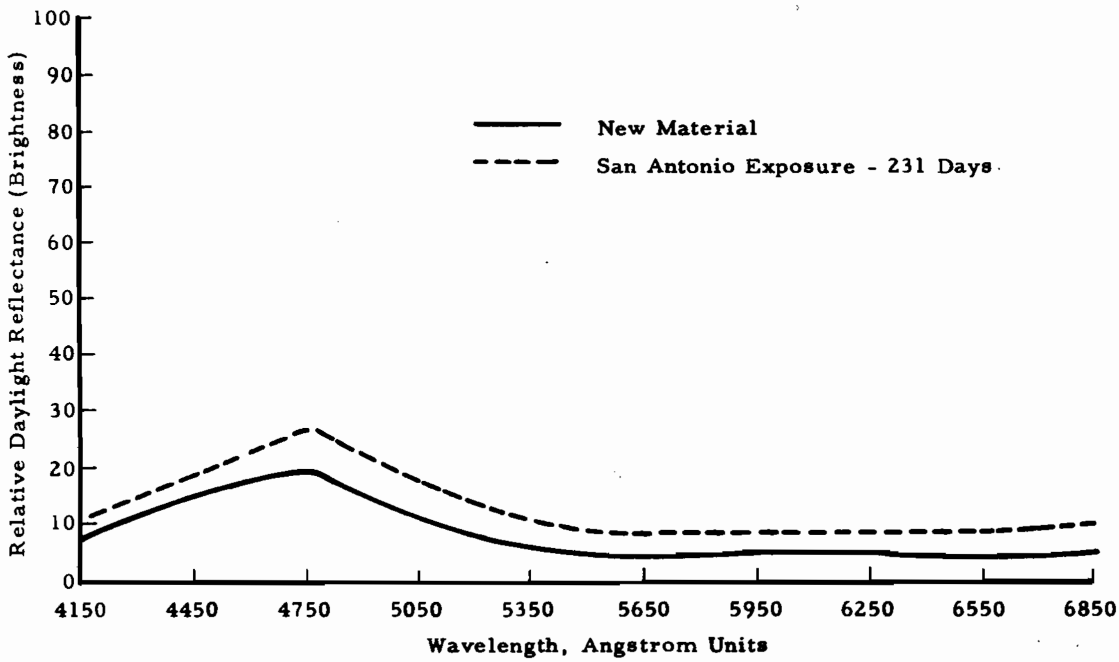


FIGURE 24. SPECTROPHOTOMETER CURVES OF BLUE REFLECTIVE SIGN-FACING MATERIAL SHOWING EFFECTS OF OUTDOOR EXPOSURE ON COLOR AND BRIGHTNESS

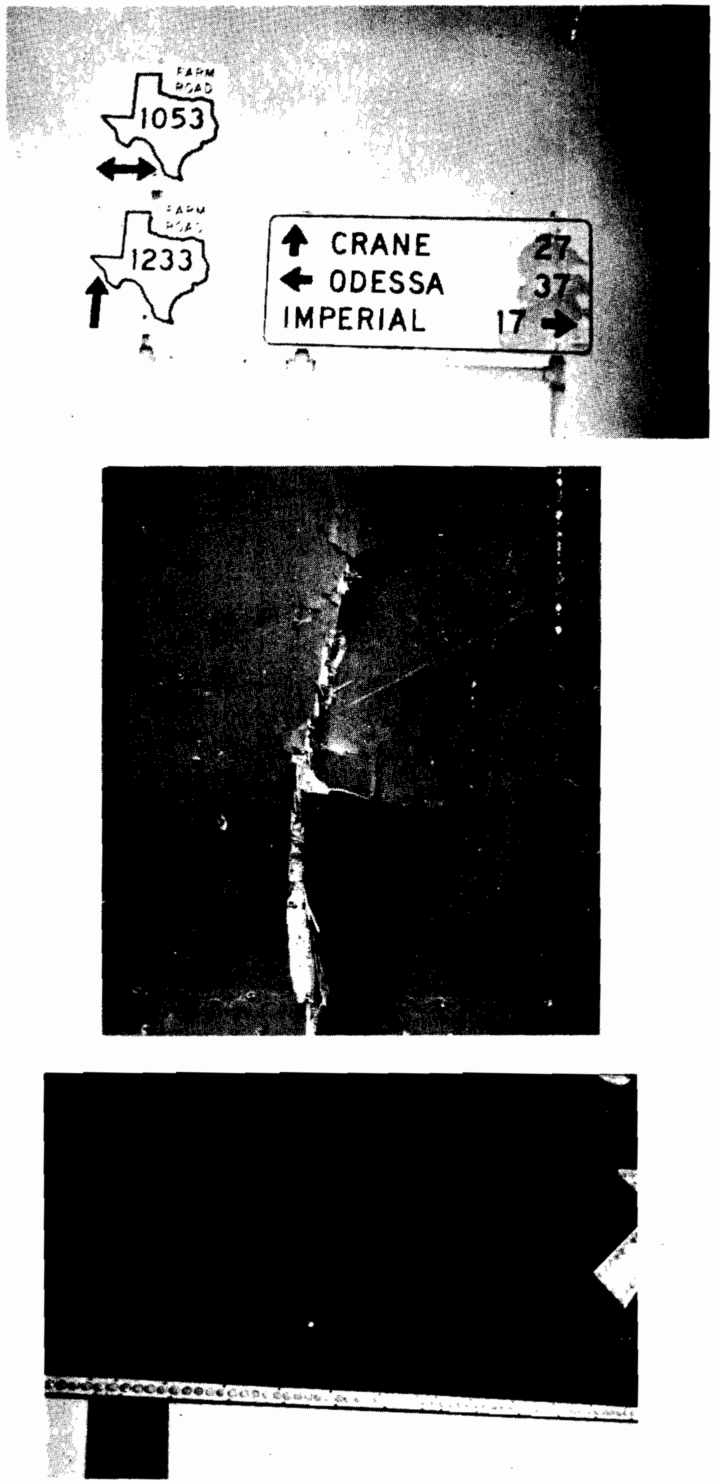


FIGURE 25. EXAMPLES OF SIGN DAMAGE: TOP - WIND-BLOWN SAND ABRASION ON 2-YEAR OLD SIGN. MIDDLE - EXTENSIVE DAMAGE BY VEHICLE ON 1-YEAR OLD SIGN. BOTTOM - DAMAGE BY THROWN OBJECTS - VANDALISM ON 1-YEAR OLD SIGN.

over the duration of a 39-week period. The signs monitored were located along relatively heavily traveled sections of Interstate 35 and Interstate 10 and at a major intersection and interchange of these highways on the west and northwest sides of the city. Table XXV shows results of observations made during this work. There was considerable evidence of damage due to vandalism, the most common and serious of which was produced by impact of various thrown objects and bullets. Signs on and near gores appeared to be the most frequent targets. Extensive damage was noted on numerous signs located along highways where shoulders were surfaced with gravel or crushed rock. Several illuminated overhead signs were found to have suffered from vandalism as well as through deterioration from other causes. Of relatively complex construction, these had facings of porcelain enamel on thin-gage aluminum. Under night illumination, some exhibited very noticeable variations in shading across the face, and many small, dark and bright spots. In numerous cases, damage from unidentified flying objects was serious even in cases where the facing was only dented. Some sign backings consist of structures that are internally reinforced with fiber honeycomb. In some of these, the weep-holes frequently were plugged, allowing the cavity between the front and back surfaces to accumulate water. Staining of the facing had occurred as the water leaked out at the first convenient opening. Bulging had also occurred.

b. Causes for Sign Replacement

During the study, it was necessary to obtain information on the reasons for the removal and replacement of signs. Some data were obtained by direct observations, as described in the previous section "a."

Texas Highway Department maintains a sign "boneyard" at one of the area maintenance warehouses where discarded signs are accumulated for later rehabilitation. An examination was made of a great many of these signs. Because of the vast number and types of signs available for inspection, it was decided to count and look at only a portion of them. An estimate indicated a total of between 6,000 and 8,000 signs had been accumulated. Of these, 1,500 representing a good cross section of types were examined to determine the reasons for removal from service. Table XXVI lists the type of sign, quantity, and general reasons for removal. The table does not include any large Interstate signs fabricated with plywood backing. Many of these are salvaged for reuse of the plywood when possible; if not salvageable, they are destroyed.

It was not possible to determine how long these signs had been in service, even though many of them were dated as to when they were constructed and/or erected. The reason for this is that a sign may have

TABLE XXV SUMMARY OF CONTINUING OBSERVATIONS OF SIGN DAMAGE DEVELOPMENT

	Type of Sign	Location: Facing Traffic	Damage		Relative Location on Sign	No. of Holes, Marks, Patches at Zero Time	No. of Holes, Marks, etc., on 6-14-66**	Observed No. of Weeks
			Type	Probable Cause*				
1.	Green, exp. lens, 12' x 23'	Westbound Loop	Scuffs, tears, patch	Rocks, UFO*	Lower left	6	6	39
2.	Green, exp. lens, 8' x 16'	Northbound Expr	Holes	UFO	Lower left	1	4	39
3.	Green, exp. lens, large	Northbound Expr	Dents	Bottles	Lower left	0	3	39
4.	Green, exp. lens, 4' x 8'	Northbound Expr	Bullethole, reflector out	Vandalism, UFO	Lower center	2	8	39
5.	Green, exp. lens, large	Northbound W. Loop	Breaks, scuffs, tears, reflectors out	Mostly vandals & rocks, bottles, cans, etc.	Lower left	15	10	39
6.	Green, exp. lens, large	Northbound W. Loop	Extensive, plus weathering	Mostly vandals & rocks, bottles, cans, & weathering	Mostly left half	28	29	32
7.	Green, exp. lens, 4' x 4'	Southbound Expr	Reflectors broken	UFO's	Lower left	10	0	39
8.	Green, exp. lens, large	Southbound Expr	Break, reflectors	Bottle & UFO's	Lower left	3	3	39
9.	Green, exp. lens, 4' x 4'	Northbound Expr	Gouged, breaks, scuffs	Bottles, cans, UFO's	Left half	5	0	39
10.	Green, exp. lens, large	Northbound Expr	None	-	-	0	0	39
11.	Green, exp. lens, large	Northbound Expr	Breaks, scuffs, gouged, hole	Rocks, UFO, bullet	Lower left center	3	0	39
12.	Green, exp. lens, 4' x 4'	Northbound Expr	Break, scuffs, 9 broken reflectors	UFO's	Lower left	2	0	39
13.	Yellow exit speed	Northbound Expr	Break	Bottle	Center	1	0	39
14.	Black Enamel, large	Southbound Highway	Paint flaking, scuffs, breaks, bulletholes	Weather, UFO's, rocks, vandals	Left side	7	11	39
15.	Green, exp. lens, large	Southbound Expr	Breaks, gouged	Rocks	Left side	0	3	39
16.	Green, exp. lens, large	Southbound Expr	Breaks, gouges, scuffs, reflectors out	Rocks, bottles, UFO's	Left side	0	6	39
18.	Yellow exit speed	Southbound Expr	Gouge	UFO	Left side	0	1	39
19.	Green, exp. lens, large	Southbound Expr	Large area bruise, reflectors out	UFO	Lower left	1	1	39

* UFO designates unidentified flying objects.
** A decrease in number of holes, etc., on 6-14-66 indicates patching has been done.

TABLE XXVI. REASONS FOR REMOVAL OF 1500 SIGNS FROM SERVICE

Type of Sign	Quantity	Reason for Removal	
BOP 24" × 24" info	200	Low brilliance	Caused by various mechanisms such as fading, weathering factors, being dirty, scuffed, etc. Very few were damaged by being struck by objects; some had bullet holes.
BOP 18" × 18" info	75	Low brilliance	
BOP 8" × 20" info	250	Low brilliance	
BOP 36" × 36" info	75	Low brilliance	
BOP 24" × 48" info	35	Low brilliance	
Miscellaneous - BOP, reflective sheeting and enamel	175	Low brilliance	
BOP yellow yield	60	Low brilliance	
Route marker shields	130	Obsolete	
Yellow stop signs	100	Obsolete	
Miscellaneous - BOP, reflective sheeting and enamel	400	Not repairable - extensive damage by impact, vandalism, etc.	

Note: BOP designates beads on paint.

been removed from service, stored for a time at a county warehouse, stored at a District warehouse for further accumulation, and then grouped for shipment to the central warehouse. At this point, some of the signs may be shipped to the Austin sign shop for renovation; others may wait six months or more before being moved out. Thus, a sign found to be dated 1961 may have been removed from service at any time since that date.

However, the information in Table XXVI does indicate that about 60% of the signs probably were removed for reasons of low brightness, and about 27% because of extensive impact damage. The remaining signs were removed because of obsolescence.

Figures 26 through 29 are photomicrographs taken of portions of signs which had been removed from service. Shown in fine detail are some of the results of degradation and reasons for diminished brightness.

6. Instrumentation Studies

A portion of this program was directed toward the development of instrumentation and systems that might be used for field evaluation of signs in service, particularly at night. Primarily, such equipment would be utilized to obtain data on photometric properties of reflective signs and would make it possible to rate their nighttime performance and serviceability. The desirable features of compactness, mobility, ease of operation, accuracy and reliability were among the requirements considered in connection with the equipment.

It is likely that useful methods and systems can and will be developed for field use in monitoring sign performance and serviceability at night. However, findings of this study have indicated that the use of instruments for field measurement of specific values for photometric properties of signs likely will not be accomplished in simple fashion. Among the areas of potential difficulty to be considered are the following:

...Instrument manufacturers who were contacted expressed opinions that current equipment models capable of making acceptable measurements are not adaptable to transport and field use but felt that, with markets justifying, adequate units can be designed and built.

...The positioning of the equipment with relation to target signs will require adequate off-pavement maneuvering area or a provision for adjusting signs so that desired incidence- and divergence-angle conditions can be

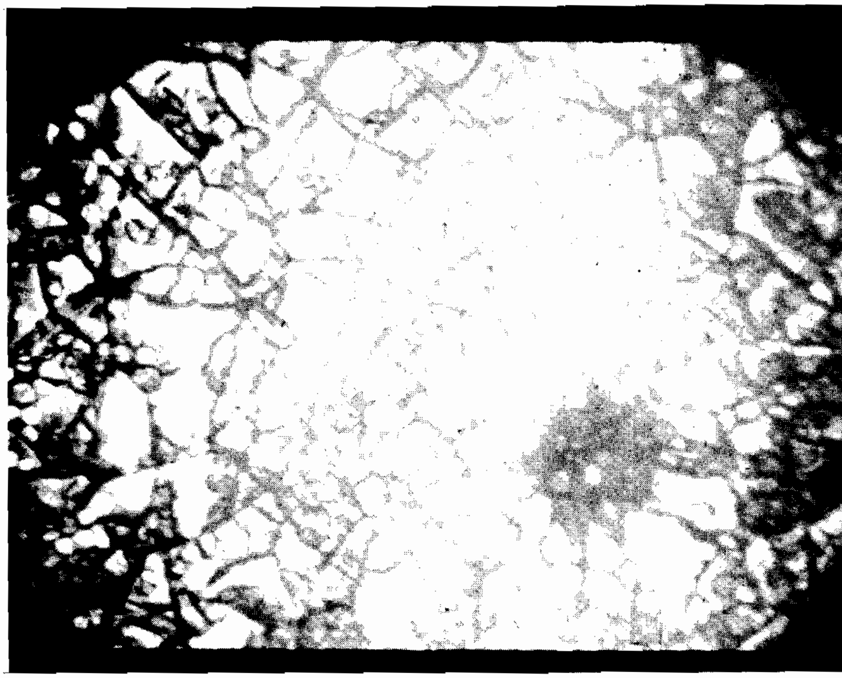


FIGURE 26. PHOTOMICROGRAPH OF FLAT-SURFACE TYPE OF SIGN-FACING SHOWING MICROCRACKING DEVELOPED AFTER ABOUT 4 YEARS' SERVICE EXPOSURE. Magnification 30X.

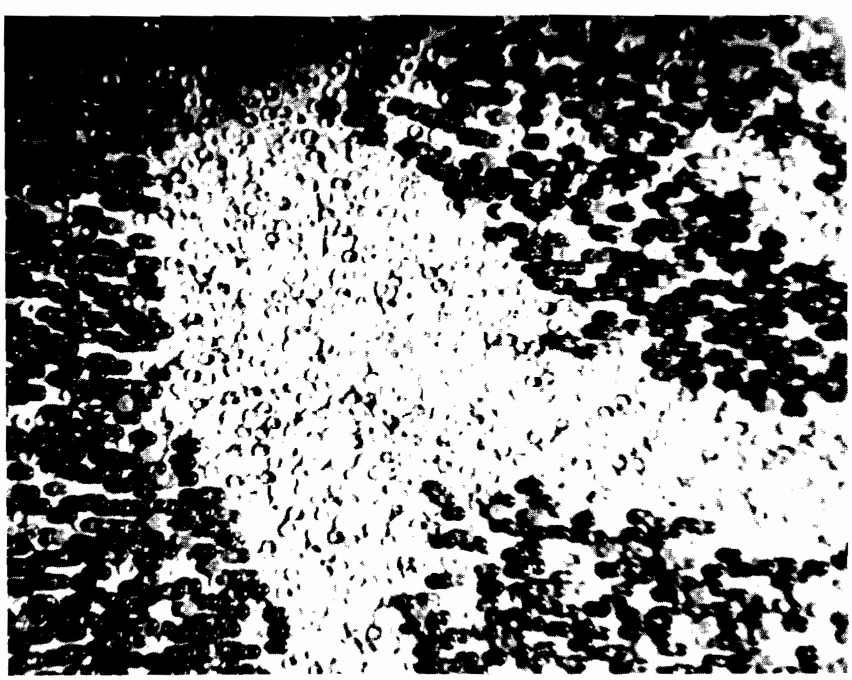


FIGURE 27. PHOTOMICROGRAPH OF BEADS-ON-PAINT TYPE OF SIGN-FACING SHOWING LOSS OF BEADS CAUSED BY IMPACT. Magnification 30X.

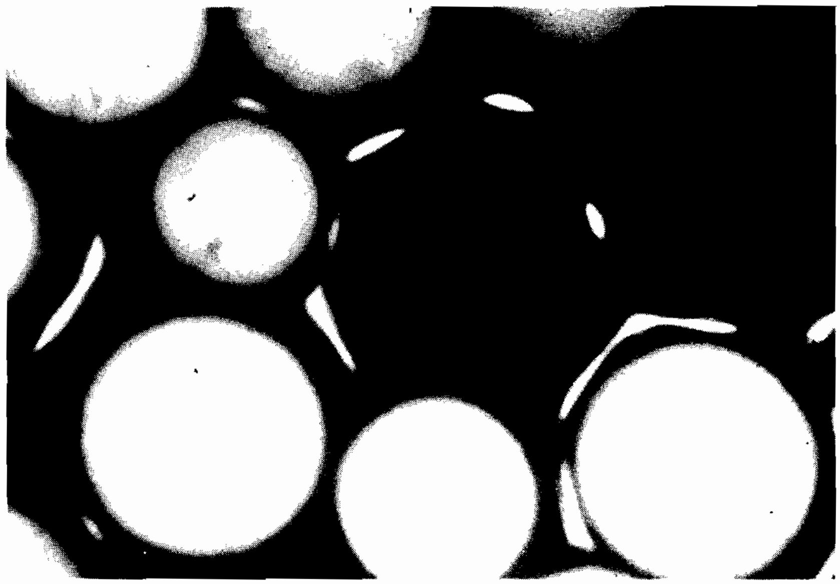


FIGURE 28. PHOTOMICROGRAPH OF GLASS BEADS IN TYPICAL REFLECTIVE SIGN-FACING SHOWING VARIATION IN SIZE OF BEADS AND TWO DARK AREAS WHICH ARE NONREFLECTING OPAQUE BEADS. Magnification about 500X.

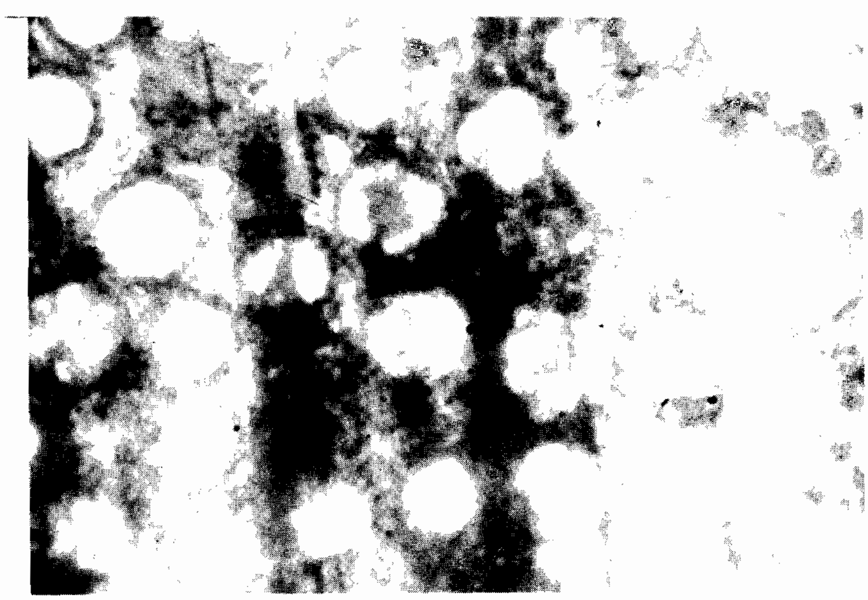


FIGURE 29. PHOTOMICROGRAPH OF SIGN-FACING SHOWING HOW ABRASION AFFECTS REFLECTIVE PROPERTY. SIGN HAD BEEN REMOVED FROM SERVICE. Magnification about 60X.

obtained. On highways, divergence angles of 3 and 4 degrees are obtained only at distances of less than 100 feet from most signs.

... Use of test distances different from those employed in photometric tunnels will produce data that cannot be correlated with those obtained under standard conditions unless compensating factors are applied. Use of test distances of less than 50 feet introduces two sources of error: 1) the angular size of the light source and photometer apertures; 2) the failure of the inverse-square law to apply exactly at short test distances.

... Due to interference and vibrations from traffic, the time required to obtain reliable measurements may be excessive.

7. Analysis of Texas Highway Department Records and Data on Signing

The Texas Highway Department has records and data on signing materials dating back to 1960. Most of the information consists of results of acceptance tests performed on samples from shipments of materials received for use in highway signing. Much of the data are in the "as-taken" condition and are on forms appropriate for recording results of the various tests; reduction to meaningful form will be necessary in many cases.

An attempt was made to correlate some of the test results with a somewhat limited amount of data available on results of examinations of panels that had been subjected to outdoor exposure. Findings of this work were inconclusive. Analysis of the data could be used to determine the constancy and variances that have occurred in certain properties of the materials over relatively long periods of time. However, since the records pertain to new materials and do not cover a wide range of materials considered pertinent to this program, such analysis was not made.

During contacts with personnel of the Highway Department, it was reported that work had been done in efforts to correlate the results of observations on similar sets of sign-facing material test specimens subjected to outdoor exposure and to accelerated and simulated weathering conditions in environmental test equipment. Results of the work were said to show reasonably good correlation with respect to some manifestations of materials deterioration as evidenced, for example, by similar cracking in specimens exposed to the two types of exposure.

8. Backing Materials

Studies of backing materials were carried out primarily in view of the close relationships between these sign components and facing materials. Emphasis was placed on determining if and how the characteristics and behavior of backings influence the performance and serviceability of facings. Accordingly, most of the observations made were on samples of backings to which the various generic classes of reflective facings had been applied. The principal materials examined were those grades and thicknesses of plywood, steel, and aluminum commonly used in highway signing.

a. Plywood

Results of this work have shown that plywood backings may have some adverse effects on the performance of some types of reflective facings. Among these are:

1) Irregularities in surface smoothness of some plywood samples - due to wood grain structure, tool marks or surface damage - were of sufficient magnitude to be transmitted through facings of reflective sheeting with the result that reflectance was not uniform over the face of a sign when viewed from different incidence angles.

2) In certain normal service environments - South Florida, for example - some plywood panels exhibited delaminating tendencies which resulted in slight curvatures along the edges and attendant variations in the pattern of reflectance. The swelling of the wood when wetted in laboratory studies was found to produce similar conditions.

3) Of the principal materials examined, plywood backings exhibited the least resistance to damage by impact and offered the least protection against rupture to facing materials.

4) Plywood was found to be more susceptible to damage during handling and sign fabrication than either steel or aluminum. Damage to the plywood was often found to have some effect on the performance of applied reflective sheeting. Repair of damaged plywood backings is not accomplished easily and, in fact, may be more costly than replacement

b. Steel

Backings of steel were not used as extensively in this work as were those of plywood and aluminum. This was primarily due to an indication that the Texas Highway Department used steel sign blanks in only about 20 to 25% of the signs requiring single-panel backings.

In general, steel backings were found not to present significant problems with respect to sign fabrication or adverse effects on the performance and serviceability of facing materials. When properly protected against corrosion (rusting), they were weather-resistant and durable. Lack of surface smoothness on some materials caused nonuniform reflectance in sheeting facings, but not to a serious degree. Staining and blistering of sheeting facings and reduction in reflectance often were found in areas of steel corrosion, particularly around bolt and bullet holes or dents caused by flying objects. Repaired and reclaimed steel backings often exhibited areas where protective coatings had been broken, with the result that corrosion had occurred.

c. Aluminum

Aluminum backings examined in this work were found to be resistant to weathering, and there was little to indicate that they adversely affected the performance of sign facings. Having the smoothest surfaces of all of the backing materials studied, aluminum reflective-sheeting combinations were easy to work with, both in sign fabrication and handling. Panels faced with reflective sheeting showed some evidence of corrosion after exposure in South Florida, with a slight loss of bonding at the edges of specimens. In repair and reclaiming operations, difficulty in straightening aluminum sign blanks was reported by highway department personnel.

IV. DISCUSSION AND CONCLUSIONS

The tasks performed and results obtained during this study have provided a reasonably comprehensive background for: 1) judging the adequacy of test methods and equipment needed to identify and evaluate those qualities of reflective sign-facing materials necessary for optimum sign performance and serviceability, 2) delineating objective criteria for specifying such qualities, and 3) establishing test procedures and requirements for evaluating signing materials with respect to these criteria. The overall investigation has produced information of sufficient quantity and character to serve as a reasonable basis for judging the adequacy of current performance specifications for sign-facing materials. Studies required for characterization of the materials involved examination of their structural features, fabricability, capability to perform as required, and behavior under various conditions. Related to characterization was determination of the manifestations of deterioration from various causes and of associated effects on qualities and properties of reflective facings.

The state-of-the-art of manufacturing sign-facing materials and of fabricating signs from them is in a development stage, judging from many findings of this work. Throughout the study, new and/or improved products were received from manufacturers, representing their efforts to improve quality and performance characteristics. Though designed and produced to serve a common function, the reflective sign facings studied differed somewhat as to basic materials employed; use of the various types of facings required different methods of sign fabrication. Other differences were noted in facing structures, performance behavior, durability, effects of maintenance, repairability, and so on. Because of the varying nature of the materials, the procedures, test methods, and equipment used to identify and study the qualities necessary for optimum performance and serviceability were found to be applicable to some but not to others. Accordingly, it seems clear that objective appraisal of the qualities of reflective signing materials should emphasize examinations which provide information on: 1) those performance capabilities that are vital to sign function and purpose, 2) the ability to retain such capabilities for reasonable use-life periods under normal service conditions, and 3) the ability to resist degradation during maintenance. This points up the need for specifications which are oriented toward performance rather than materials, fabrication, and other features. Acceptance tests are important and necessary, but only as a means of determining whether new materials meet requirements with regard to vital properties such as reflectance, color, and perhaps one or two others.

Discussions of areas of primary interest and conclusions drawn from results of studies are presented in the following sections.

Photometric Properties

Qualities of reflectance and color are of primary interest in signing materials, the first because it denotes that property which makes a sign message visible at night, and the second because it signifies the nature and degree of importance of the message. The two are related in current reflective signing practice, which takes advantage of color and brightness contrast as a means of highlighting the message against a subdued background. As compared to measurement of many of the other properties of sign-facing materials, determination of values for reflectance and color is one of the more difficult tasks that must be accomplished for appraisal of sign quality, performance and serviceability.

Reflectance. In this program, reflectance measurements were made through the use of the photometric tunnel and associated equipment previously described. Such a facility is not overly complicated either as to design or operation, and provides an adequate means of appraising the retroreflective qualities of reflective facing materials under dry and wet conditions; measurement values can be reproduced within reasonable limits. There are other more or less complex systems that can be used with an equal degree of accuracy.

The reflectance of sign facings examined varied over a wide range in new materials as well as in those subjected to outdoor exposure, and was indicated to be more affected and sensitive to deterioration than any other single property. Reflectance is therefore considered to be a rather effective index of materials durability as well as sign performance and serviceability. Accordingly, this property might well be a principal feature around which to write performance specifications for reflective signing materials.

A problem exists in comparing reflectance data obtained through the use of the different photometric property measuring systems. The problem is more pronounced with colored retroreflective materials than with white materials. There is a need for calibration standards which would be applicable to all systems, making it possible to correlate the results obtained from one facility to another. The fulfillment of this need would also justify consideration of defining more clearly the acceptable upper and lower values in objective specifications for reflective sign-facing materials. Current specifications provide for minimum values but do not establish upper limits for the amount of light reflected. On the premise that the amount of light reflected can be excessive, it is reasonable to consider that upper limits should also be specified. Among sign-materials manufacturers, highway department personnel, and others working in highway signing and who were contacted during this program, it is generally felt that some sign-facing materials reflect too much light. It is noteworthy that specifications have been examined which provide for a minimum brightness value of 40 candle power per foot-candle per square foot for silver-white reflective sheeting at 0.2-degree divergence angle and 0-degree incidence angle. Of the silver-white facing materials on which reflectivity was measured in this study, several had values of over 200 candle power per foot-candle per square foot, with one reaching 250.

Brightness, per se, is only one of the criteria on which to judge the night legibility of a sign. Observations have indicated that the contrast between brightness of the lettering and that of the background is also important. If some realistic basis can be established for the optimum degree of contrast, values for brightness of lettering and background might be specified.

Color. Although findings of this program have shown that colors of reflective sign-facing materials undergo changes due to weathering and other service conditions, the changes were relatively minor and not considered serious. Reds and yellows have appeared to be the least stable, but there have not been indications that these colors deteriorate so rapidly or change so grossly as to have pronounced effects on sign performance and serviceability. Particularly severe environments may produce such effects, but it is highly probable that instead of color change, degradation of reflective qualities would be the reason for sign replacement.

Of the methods of measuring color of sign facings, that employing a spectrophotometer with a reflectance attachment is felt to be very adequate and was utilized in this program. The data derived from measurements with such equipment will accurately describe color and color differences. Among the factors which led to the choice of a spectrophotometer in this work were: 1) the apparatus does not depend on the use of filters for color determination; 2) calibration of the instrument is a relatively simple operation and is made through the use of a dependable standard; 3) the equipment is not expensive and is simple to use; and 4) results of measurements are reproducible for a given color. Considerable importance was also placed on the point that spectrophotometric measurement is the basic method for color determination.

As in the case of reflectance, a need is indicated for standardization of methods and techniques of color measurement whereby it will be possible to correlate the results obtained by various instrument systems used from one facility to another. This problem does not appear to be as serious as in the case of reflectance, since color is regarded as being secondary to message clarity and legibility. However, it is important that data on color measurements be in reasonable agreement and expressed on a uniform basis so that specifications can clearly define values and limits. At the present time, it is felt that laboratory and/or field determination of whether daytime colors of highway signing materials fall within acceptable limits can be made through visual comparison with available color standards. In making such comparisons, attention should be given to color differences which may be evident in standards obtainable from various sources. Obviously, if standardization of sign colors on a national scale is a primary consideration, then a single set of standards should be used.

Determination of the qualities of sign-facing colors at night poses a particular problem. The visual comparison method indicated above for daytime color determination is not applicable to reflective facings at night because of reflectance interference factors; these vary from one color to another. Also, the use of standards for nighttime visual color comparison seems impractical, since it is likely that their reflective qualities would be subject to deterioration from many causes, resulting in wide variation in results. Thus, if determination of colors of reflective facings is required in terms of specific values, spectrophotometric measurements must be made.

Deterioration and Durability of Signing Materials

The performance and findings of laboratory and related field studies in this program have revealed much concerning the relations between deterioration of signing materials -- particularly reflective facings -- and sign serviceability and use-life. Though the emphasis was placed on the effects of deterioration rather than on the chemistry and physics of how and why it occurs, some information was developed on the tentative identity and functioning of the basic mechanisms involved. However, this information is subject to confirmation through comprehensive investigation that was not possible within the scope of this program.

Briefly, the basic mechanisms causing the deterioration of sign-facing materials are chemical and/or physical in nature. Deterioration in turn affects performance, serviceability, and use-life. Some of the basic mechanisms indicated from observations in this study are indicated below, with attendant effects on signing materials.

.... The breakdown of plastics, certain pigments, organic constituents of paints and other materials during exposure to environmental conditions including sunlight, moisture and temperature changes, is common. The effects of this mechanism may be seen as cracking, color change, loss of glass beads in beads-on-paint facings, reduction of reflectance, etc.

.... The corrosion of metals, principally steel, is a well-known form of deterioration. Its effects may be manifested as staining or discoloration of sign facings, separation of facings from backings, reduction in reflectance, blistering of facings, and so on.

.... Differentials in coefficients of expansion of materials exist in many composite structures, including signs. Effects of significant mismatches between materials may be noted by separation of sheeting facings from backings, loss of beads from beads-on-paint facings, cracking of facings.

. . . . Hardening or embrittlement of adhesives and plastics at low temperatures can occur. Effects may be seen through separation of facings from backings, cracking of facings, and chipping under even small impact forces.

. . . . Erosion by wind-blown materials and abrasives in cleaning materials is known to occur frequently. Effects of this mechanism generally are manifested by reduction of reflectance, reduced legibility of message, removal of protective coatings from backings and other sign parts.

Based on findings of this study, several general observations may be stated with regard to relations between durability, performance and use-life of reflective sign-facing materials. In many cases, sign facings consist of rather complex composite structures containing retroreflective glass beads, binders, reflective media, surface coatings, and other elements. Durability of the facings is a function of the resistance to deterioration of the constituent materials; failure of a facing to perform as required can often be traced to degradation of a particular component in its structure. A case in point is the transparent covering on the flat-surface type of reflective sheeting. Degradation of this part of the structure by any of a number of mechanisms often causes a reduction in light transmission and attendant loss in reflectance by the sheeting. Similarly, in facings of the exposed-lens type, deterioration of the matrix holding the retroreflective glass beads can lead to loss of beads and reduced reflectance. The performance of the facing materials is thereby adversely affected. Under differing service conditions, the use-life of signs can be expected to vary according to the rate, severity, and nature of deterioration. It seems clear that various climatic and other environmental conditions can and do cause differences in all of these for a given sign-facing material.

Aside from damage due to vandalism and collision, the principal reason for replacement of signs has appeared to be loss of reflectance by facing materials. Decisions on removal and replacement of signs are based on the judgment of highway department personnel as dictated by results of visual inspection.

Due to the limited duration of panel exposure tests, lack of sufficient monitoring of environmental conditions, and infrequent examination of exposed samples, comprehensive investigation of the durability of sign-facing materials was not possible during this program. Some limited indications of weatherability characteristics were obtained through examination of panels after exposure, but generally these were not diagnostic. There is a need for studies that will provide information on durability and use-life of sign-facing materials. In the absence of suitable accelerated tests, such work would have to extend over a period adequate for the development, identification, and evaluation of those features which account for durability.

In view of the close relationship between facings and backings of signs, the possible influence of the latter on durability, performance and use-life cannot be neglected. Most backing materials in current use exhibit good durability -- some because they are inherently resistant to weathering and others because they have been treated to render them so. In this study, degradation of some specimen backing panels was found to have adversely influenced the performance of facings after relatively short periods of outdoor exposure.

Physical and Mechanical Properties

Numerous physical and mechanical properties of sign-facing materials were studied in attempts to determine which might be of such low order as to be main contributors to poor durability and shortened use-life of signs. Another purpose of this work was to gain an indication of the need for specifying values for certain of these properties as a means of assuring optimum sign quality and performance.

With few exceptions, the principal value of studies of physical and mechanical properties appears to be that they provide a more complete picture of the character of facing materials and their relationship to other parts of signs. Measurements of adhesion, elongation, tensile strength and flexibility might be meaningful if experience has shown that optimum sign performance is dependent on certain values for those properties. However, the methods and equipment required to determine these property values would be different for various types of facings, as for example, reflective sheeting and beads-on-paint. In the case of tests to measure impact resistance, results relate to the combined behavior of facing and backing materials. However, most cases of damage to signs by impact of flying objects represent abnormal conditions.

Measurement and tests of abrasion resistance are considered useful as a means of gaging the effects of windborne sand, or other materials, on facings. In order to be objective and realistic, the abrasive media used in such tests should be representative of those encountered under normal service conditions.

Since it was found that facing materials vary as to retention of dirt, determination of their cleanability is important. Assuming the accumulation of dirt under normal conditions, a simple procedure of spraying or flushing with water minimizes the occurrence of deterioration due to cleaning. In cases of severe soiling or staining, it is obvious that more intensive cleaning measures must be employed. However, from the standpoint of a standard cleanability test, such conditions would not be considered.

V. RECOMMENDATIONS

The following recommendations are based on findings of this program and relate to specifications tests and evaluations, and further investigations of sign-facing materials.

Specifications

. . . . Specifications should be performance-oriented, with minimum reference to specific types of products, except when service conditions warranted or when other objective causes are to be satisfied.

. . . . Specifications should be realistic and reasonable.

. . . . Acceptable limits should be expressed in clearly defined standard units of measurement, with reference to a particular property.

. . . . Specifications should be written only for those properties or characteristics identifiable with acceptable performance.

Tests and Evaluations

. . . . Test and evaluation methods and procedures should be capable of providing meaningful data.

. . . . Standardized test and evaluation procedures and equipment should be used.

. . . . Test and evaluation methods, procedures and equipment should be such that results are repeatable and reproducible within reasonable limits.

. . . . Test and evaluation methods and procedures should be reasonably simple and uncomplicated.

Further Investigations

. . . . Recommendation is made for a program to obtain data and information on the behavior, performance, and serviceability of sign-facing materials under different service conditions. This could be carried out by selecting a number of sites where different climatic and other conditions prevail and exposing various materials for extended periods. Studies of materials would be made at appropriate intervals for determination of the effects of exposure to the various conditions. Information would be obtained on overall durability, modes and rates of material deterioration, use-life expectancy, differences in materials behavior, etc. It is anticipated that such a program should extend over at least a three-year period and perhaps longer.

. . . . A study is recommended for examination and analysis of sign-materials specifications of the various states, the objective being development of information to serve as a basis for consideration of a uniform code.

. . . . A program is needed to study in detail the mechanisms causing deterioration of sign facings and to utilize findings in the development of accelerated tests for rapid estimation of life expectancy.

APPENDIX

APPENDIX

Bibliography on Highway Signing

A bibliography has been included as an aid to those desiring a closer look at the comprehensive field of highway signing. The various publications included cover the whole general area of signing: materials, application, construction/fabrication, optics, night vision, driver psychology, sign effectiveness, color, instrumentation pertaining to all phase of signing, patents, and general interest articles. In compiling the bibliography on highway signing, it would be proper to examine some of the basics which the term "signing" is taken to include:

1) Flat surfaces of any reasonable size, displaying readable text.

2) Flat or nonflat surfaces displaying meaningful symbols (striped posts, directional arrows, pavement, curb or railing markers, etc.).

3) Bright objects which are generally visual point sources (steady or flashing lights, delineator reflector buttons, etc.).

The fundamental end purposes of signing are:

1) To be seen or noticed:

    a) Expectedly (information).
    b) Unexpectedly (warning, information).

2) To deliver a message:

    a) Legibility (pure or glance, as applicable).

3) To accomplish 1) and 2) with a minimum of distraction:

    a) In a negative sense (through poor legibility, excessive text versus assimilation time, etc.).
    b) In a positive sense (through excessive size, brightness, contrast, etc.).

In general, the previous factors properly belong in the field of the psychology of perception, and, in these areas, it appears that adequate and competent work is being prosecuted, as is reflected in the bibliography. There are elements of reduction to practice, however, in which some effort should be directed. Although much has been done in the area of perception and vision, it is difficult to determine from the literature the mode of translation over to practical photometric (or other optical) applications; workers in these fields are generally oriented toward the clinical aspects of the subjects.

The problem of relating the requirements of the psychological and physiological requirements of human vision to the photometry of highway signing has apparently been neglected, as few fundamental and concise publications on this matter were found during this search. Literature on those subjects pertinent to the specific area of this study on the characterization of sign-facing materials was found to be very limited.

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