

R-741

AN EVALUATION OF
"EFFECTIVE AND DEPENDABLE" REFLECTORIZATION
FOR REGISTRATION PLATES

LAST COPY
DO NOT REMOVE FROM LIBRARY



MICHIGAN DEPARTMENT OF STATE HIGHWAYS

AN EVALUATION OF
"EFFECTIVE AND DEPENDABLE" REFLECTORIZATION
FOR REGISTRATION PLATES

Research Laboratory Section
Testing and Research Division
Research Project 69 G-172
Research Report No. R-741

Michigan State Highway Commission
Charles H. Hewitt, Chairman; Wallace D. Nunn, Vice-Chairman;
Louis A. Fisher; Claude J. Tobin; Henrik E. Stafseth, Director
Lansing, May 1970

CONTENTS

Page

INTRODUCTION	1
Program Concept	1
Sample Procurement	1
Sample Limitations	3
TESTING SEQUENCE	5
Series 1 Tests	5
Photometric Testing	5
Color Testing	5
Gloss Testing	5
Series 2 Tests.....	7
Weatherometer Testing	7
Corrosion Testing	7
Series 3 Tests	7
Heat-Shock Testing	7
Flexibility Testing	7
Series 4 and 5 Tests	7
Scrub Testing	8
Sand Abrasion Testing	8
Heat and Humidity Resistance Testing	8
Flexibility Testing	8
Solvent Resistance Testing	8
Sulfide Stain Testing	8
Flammability Testing	8
REFLECTORIZING MATERIALS STRUCTURE	9
3M Co. Reflective Sheeting	9
3M Cudit	9
Flex-O-Lite	9
Prismo	11
RESULTS OF TESTING	11
Specific Luminance	11
Color	11
Artificial Weathering	13
Corrosion	15
Heat Shock	16
Scrubbing	16
Sand Abrasion	16

INTRODUCTION

On July 17, 1969 the Governor of Michigan approved Public Act No. 44 which required, in part, "...effective and dependable reflectorized material..." for use on registration plates. The bill also required the promulgation of specifications by the Department of Administration in conjunction with the Departments of Corrections, Highways, and State. This led to the formation of a Reflectorized License Plate Committee which was given the responsibility of preparing specification recommendations for a two-year durability reflectorization system by January 1970. Recommendations were expected to be developed in part from studies of adhesion, reflectivity, angularity, and legibility of reflectorized plates as well as a study of adhesion performance of validation stickers. The Committee requested the Department of State Highways to develop these recommendations within 6 months. The Research Laboratory of the Testing and Research Division was assigned the test program by the Committee.

Program Concept

A Departmental meeting was held to clarify the concept of the test program. It was noted that results of testing were expected to provide an effectiveness comparison of reflectorizing materials and that the program was to include consideration of registration plates as a safety warning system. The effectiveness of safety warning systems was assumed to be capable of definition and, therefore, the evaluation of effectiveness could become a basis for defining effective reflectorization. For example, comparison of vehicle stopping distances with visual detection distance of registration plates was expected in the safety system evaluation. The determination of nighttime legibility of reflectorized plates, nighttime reaction distance to reflectorized plates, and durability were also proposed.

Sample Procurement

Materials for the test program were requested by the Department of Administration from the following companies: 1) Minnesota Mining and Manufacturing (3M), 2) American Decal and Manufacturing, 3) Flex-O-Lite Division of General Steel Industries, 4) Prismo Safety Corporation, 5) Cataphote Corporation, and 6) Fasson Products. The request required that the sample registration plates have a reflectorized background; that six plates each of one-, two-, and three-year durability materials (gold color and white color) be submitted; and that the gold color match a specified color chip or be the manufacturer's nearest available standard color.

Sample Limitations

Visual evaluation of the initially received plates, indicated that the study would be seriously limited. Therefore, the scope of these limitations and a proposed testing program were presented to representatives of the Department of Administration and the Department of State Highways' Traffic and Safety Division.

In the presentation it was noted that lack of legend variation would make valid legibility comparisons impossible (i. e., all 3M plates and all Flex-O-Lite carried the legends shown in Fig. 1). Legibility comparisons would also be limited because differences in letter height could not be corrected by simply reducing legibility to distance per inch of letter height. Brightness differences and the inherent effects of halation would make such corrections impossible. Embossing was also expected to interfere with uniform access of test equipment to such areas.

Color changes, although such changes would not noticeably interfere with testing, were also noted. Flex-O-Lite and 3M plates changed color from a white legend on a gold background under daylight illumination to a gray legend on a white background under headlight illumination.

Definition or clarification of the intent of the term "effective reflectorization" remained unresolved but the Traffic and Safety Division representatives indicated that from a traffic engineering point of view, plate legibility at 133 ft was necessary day and night. Stopping distance was also mentioned as a basis for specifying the requisite visibility distance of plates, and the AASHO 65 mph stopping sight distance of 550 ft was suggested.

Both Departments (Administration and Highways) agreed that even though undesirable sample variations existed, tests should be performed on the samples as received since sufficient time was not available to obtain more suitable samples. Tests were to include reflectorized legend plates.

A proposed outline for conducting the test program and a sequence of tests (Series 1 through 11) as shown in Table 1 were presented, along with a request for additional samples. It was noted that the testing sequence was prepared on the basis of the five samples of each type of material submitted.

It was agreed that additional samples consisting of 6- by 12-in. unembossed blanks representing each company's reflectorized materials and also plates with legends having equal reading difficulty were necessary. A sequence of testing was also prepared for the unembossed blanks.

Table 2 describes all samples received.

Note that further reference to plates under test in this report will be denoted by the last three characters of the sample numbers shown in Tables 1 and 2.

Time limitations imposed by the artificial weathering test required that testing of the initially received embossed plates begin prior to receipt of all expected samples.

This report will present a discussion of the tests as noted, the results, conclusions, and recommendations concerning the performance of reflectorized registration plates.

TESTING SEQUENCE

Series 1 Tests

As shown in Table 1 under the Series 1 tests, one plate of each set was photometered and appearance was evaluated by determining color, reflectance, and gloss (60° and 85°). The plate was then retained as a reference or a basis for comparison for the test plates.

Photometric Testing - Photometric testing was conducted in accordance with the conditions specified in the MDSH Standard Specifications 7.26.11c, 2 (1967). Viewing angles of 1/10, 1/5, 1/3, 1/2, and 1-1/2 degrees were used in measuring orientation angles of 0, 5, 10, 15, 20, 30, 40, and 50 degrees. Geometries obtained by various combinations of these viewing and orientation angles satisfy most of the sight conditions confronting a driver.

Photometric test results were expected to provide an index of reflectorization degradation for the various tests.

Color Testing - Color was evaluated visually and instrumentally. Visual evaluations were made under nighttime viewing conditions. Daytime color was measured instrumentally in accordance with ASTM E 97-55, "45-Degree, 0-Degree Directional Reflectance of Opaque Specimens by Filter Photometry."

Gloss Testing - Gloss, 60 degree and 85 degree, was determined in accordance with ASTM D 523, "Specular Gloss."

Series 2 Tests

The second series of tests were expected to show degradation obtained after an exposure to 400 hours artificial weathering and 200 hours of salt spray corrosion, followed by a second exposure to 400 hours artificial weathering. The exposures were taken from the Department of Administration specification for "Precoated Galvanized Coil Steel and License Plate Ink." The specified exposure was used as a performance index for materials with an expected three-year durability.

Weatherometer Testing - Artificial weathering was carried-out in an Atlas Model XW-R Sunshine Arc Weatherometer with humidity control, under the conditions specified in ASTM E 42-65. The cycle consisted of alternating 102 minutes of light and 18 minutes of water spray and light. Black body radiation temperature was 140 F, and the typical relative humidity was 48 percent. Time limitations made it necessary to operate the weatherometer continuously rather than using a four-hour 'off' (recovery) time after each 20 hours of exposure as noted in the above ASTM specification.

Corrosion Testing - Each of the plates was cut for corrosion testing as specified in ASTM D 1654-61, "Standard Method of Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments." Salt spray corrosion testing was done in accordance with Method 6061 of Federal Test Method Standard No. 141a.

Series 3 Tests

The third series of tests duplicated the 400-hour artificial weathering and the 200 hours of salt spray exposure but with an additional heat-shock cycle.

Heat-Shock Testing - Heat-shock testing was conducted in accordance with the method described in the MDSH Specifications 7.26.11c, 3 (1967). Plates in this series were scored for the corrosion test as described above.

Flexibility Testing - After the exposure test, these plates were also subjected to a room-temperature flexibility test. This test was conducted according to Method 6221 of Federal Test Method Standard 141a.

Series 4 and 5 Tests

The fourth series of test plates were subjected to tests showing the effects of abrasion, and the fifth series was expected to show the effects of thermal exposure and impact.

REFLECTORIZING MATERIALS STRUCTURE

Before discussing the results of the tests it should be noted that the data obtained are applicable to the reflectorized registration plate materials submitted. Modifications in the materials, such as change of formulation, changes in color, beads, adhesive, application techniques, etc. would require additional testing. The materials used in this study are described as follows:

3M Co. Reflective Sheeting

This material consists of an adhesive film and a resin film which contain a mono layer of glass beads and a reflector film. Bead size varies from slightly less than 2 mils to 3 mils. Refractive index of the beads could not be determined. Microscopic examination of the samples showed the presence of beads with an opaque appearance. Samples 30, 31, and 97 had less than 1 percent opaque beads while Samples 33, 34 had approximately 14 percent, and Sample 98 had about 10 percent opaque beads. Samples 30, 31, 33, and 97 contained a white adhesive and the adhesive on Samples 34 and 98 was colorless. In reducing the reflective sheeting to registration plates the sheeting is applied to unembossed plate blanks. The blanks are embossed, the raised portion of the plate is inked with paint, and then the plates are dipped in a clear varnish material.

3M Cudit

This material consists of glass beads premixed in a paint. Bead size varies from 2 mils to 4 mils with most of the beads measuring slightly more than 2 mils. Refractive Index of the beads could not be determined. Microscopic examination of the samples show that the applied film was not a continuous surface but consisted of many bead sized globules. In reducing this material to plates it is understood that primer coated blanks are embossed, the reflective material is sprayed and the embossed areas are inked. Examination of Sample 58E showed no evidence of a primer coating.

Flex-O-Lite

This material consists of a single layer of glass beads on a painted surface. Bead size varies from 2 mils to 4 mils with most of the beads measuring 3.5 mils on Samples 37, 38, 39, and 93 and most of the beads measuring approximately 4 mils on Samples 36 and 95. The unembossed blanks had slightly larger beads on the multi-year material than on the single-year material but this was not consistent with the embossed blanks. Refractive

index of the beads was slightly greater than 1.91. The beaded surface was covered with a clear varnish material which may coat the top of the beads. In reducing this material to plates it is understood that primer coated and painted blanks are embossed, a tack coating for the beads is applied, the beads are dropped on, and then the plate is sprayed with a clear varnish.

Prismo

The Prismo reflectorizing system as prepared by the Prison Industries shop consisted of glass beads on a painted surface. Bead size for most beads was 6 mils and refractive index of the beads was slightly greater than 1.91. These materials were used to prepare registration plates by painting unprimed embossed blanks, applying a tack coat to the embossed areas and dropping beads onto the tack coat.

RESULTS OF TESTING

Specific Luminance

Specific luminance data for the plates used in the artificial weathering test are shown in Figure 2. The data show the effect of various plate orientation angles on specific luminance at a 0.1 degree viewing angle (typical of the viewing angle for 1,000 ft or beyond). Figure 2 also shows similar data for a 0.5 degree viewing angle typical for distances beyond 400 ft. Since plate legends cover approximately 1/4 of the plate surface, the much lower values for the reflectorized legend plates (38A) were expected. Specific luminance of a Codit plate having non-reflectorized legend on a reflectorized background would have been 60 to 75 percent of the values shown. The legend was reflectorized the same as the background on the tested sample.

Color

It should be noted here that the 3M gold color sheeting plates received initially were lighter in color than the gold specified for Michigan's 1970 plates. Apparently 3M experienced difficulty in producing the gold color because color matching problems were given as one of the reasons for the late delivery of their unembossed blanks and the plates with special legend. The latter plates were considered darker in color than the gold color specified for 1970 plates and the specific luminance was approximately 10 percent lower when compared with the plates received initially.

Artificial Weathering

The effects of artificial weathering on the materials supplied by each manufacturer are shown in Figure 3. Specific luminance of the test plate prior to weathering was considered as 100 percent and then the specific luminance values obtained during the weathering history were calculated in terms of a percentage of the pre-test or original specific luminance. Percentage of the original luminance is shown versus the orientation angle of the plate at the 0.1 degree viewing angle; and the 5 degree orientation angle. Flex-O-Lite's single and multi-year materials had approximately the same weathering characteristics. Each material showed a considerable loss in luminance after the first 100 hours of artificial weathering and 50 hours of salt spray exposure (100W-50SS). After 400W-200SS exposure each material showed a retention of approximately 90 percent of its original specific luminance and at the end of an additional 400 hours of artificial weathering (400W) the apparent loss was regained. Weathering could have eroded the paint film over or around some of the beads and may have eroded some of the protective coating material, resulting in an increased specific luminance.

With the exception of the white multi-year material, 3M sheeting materials showed a continued loss in specific luminance. The multi-year white background sheeting maintained its original luminance for the first 400W-200SS exposure and then degraded to 60 percent of its original luminance at the end of an additional 400W. The comparable white background single year material maintained 70 percent of its original luminance after the first 400W-200SS exposure and then degraded to 25 percent of its original luminance at the end of an additional 400W. The gold background material did not perform as well as the white background sheeting.

Codit (3M) showed an approximate 50 percent retention of original specific luminance at the end of 400W-200SS exposure and then showed an approximate 70 percent retention of luminance after an additional 400W exposure.

The Prismo material showed approximately the same weathering characteristics as the Flex-O-Lite single-year material.

In Figures 4A and 4B the specific luminance of the various plates is shown in order to provide a reference or comparison basis for the various reflective materials.

Color measurements throughout the weathering and exposure tests indicated little or no change in color for any of the samples. Visual estimations, however, indicated that the samples faded. Visual appearance was an important criterion in evaluating the effects of weathering and corrosion. The Appendix contains photographs obtained under diffuse lighting to simulate daytime appearance and under reflex lighting to simulate nighttime appearance.

Gloss measurements were not particularly useful for obtaining comparison data between the reflectorized sheeting and beaded paint. Beaded paint panels have a matte surface appearance and, therefore, gloss readings are very low.

TABLE 3
CORROSION CREEPAGE RATINGS
(400 hr weathering - 200 hr salt spray)

ASTM Rating	Average Corrosion Creepage in Inches	Sample No.	Manufacturer
10	0	37 A & B	Flex-O-Lite { Reflectorized (Background)
		57 A & B	Prismo
		58 A & B	3M "Codit"
9	1/64	39 A & B	Flex-O-Lite { Reflectorized (Background)
8	1/32	38 A	Flex-O-Lite { Reflectorized (Background)
7	1/16	31 A & B	3M sheeting
		34 A & B	3M sheeting
6	1/8	30 A & B	3M sheeting
		33 A & B	3M sheeting

Corrosion

Corrosion effects from the 200 hours of salt spray exposure (400 hours artificial weathering included) were evaluated according to Rating Schedule No. 1 of ASTM D 1654-61, "Standard Method of Evaluation of Painted or Coated Specimens Subject to Corrosive Environments." In Table 3, the ratings and the average corrosion creepage are given in the order of effect on each plate tested.

Solvent Resistance

The cumulative effects of the solvent immersions on the specific luminance of the embossed plates are summarized in Table 4.

TABLE 4
SUMMARY OF SOLVENT RESISTANCE

Plate Rating	Solvent		
	Xylene	Gasoline	Carbon Tetrachloride
Best	multi-year Flex-O-Lite 3M Codit	multi-year Flex-O-Lite 3M Codit	multi-year Flex-O-Lite
Inter- mediate	1 year Flex-O-Lite 1 year 3M sheeting	multi-year 3M sheeting 1 year 3M sheeting	Other materials approx. equal effect
Poorest	multi-year 3M sheeting	1 year Flex-O-Lite	

Sulfide Stain Resistance

The hydrogen sulfide treatment had the most severe effect on 3M's one-year durability sheeting, only 54 percent of its original specific luminance was retained. 3M's multi-year material retained 67 percent of its original luminance while the Flex-O-Lite one- and multi-year materials retained 77 and 82 percent of their original specific luminance, respectively.

Flexibility

Results of each flexibility test are summarized in Table 5. The test condition and sample history are shown along with results, listed in order of best sample first.

Impact

Condition results of the impact tests are summarized in Table 6. The table shows the test condition and sample history along with results, listed in order of best sample first.

Flammability

Inspection of the plates after the flammability test showed that all of the materials charred but none of the materials supported the flame. 3M's sheeting material blistered and could be scraped from the plate with a fingernail. 3M's Codit appeared to have the best flame resistance.

VALIDATION STICKERS

Results of the test on validation stickers are included here for convenience.

Reflectorized tape supplied by the 3M Co. for use as validation tags was obtained from the Department of Corrections on December 24, 1969. The tape was tested for adhesion on the various reflective materials and also for specific luminance. Tape samples were pressed onto the test plates and removal by hand (no tools) was attempted after 72 hours. The various plates tested, and the adhesion results of the 3M tape material are shown in Table 7.

REGISTRATION PLATE LEGIBILITY

Registration plate legibility was determined under various plate lighting conditions using plates with legends of approximately equal legibility distances or equal reading difficulty.

Laboratory Test

Data from 15 observers was used to select those letters and numerals which had approximately equivalent legibility and which had legibility distances near the mean legibility distance of all letters and numerals. The letters "D, K, N, P, V" were selected and numerals "0, 2, 6, 9." From these letters and numerals three letter and three number combinations were prepared. Observer legibility of these combinations was determined and, finally, those letter combinations which departed 10 feet or more from the mean legibility distance were eliminated.

Flex-O-Lite and 3M furnished plates with special legends but plates made with Prismo and Cataphote materials were not submitted. The plates were photometered. In an attempt to simulate registration plate viewing conditions, and to facilitate observer orientation, the plates were mounted on a rear bumper assembly as shown in Figure 5. The bumper was clamped to a laboratory cart such that the plate bottom height was 16 in. above the ground. Since enamel plates were not available, photographic reproductions were prepared to simulate plates with a contrast equivalent to the 1970 plates.

Daylight Legibility

Observer legibility distances were measured in the daylight under conditions shown in Figure 5. The bumper and plate assembly was pushed toward the observer until the observer read the plate legend correctly. Observers were encouraged to read until they were informed that their reading was correct.

The results as compared in Figure 6 show little difference in daylight legibility of reflectorized plates. None of the reflectorized plates are as legible as a white on black, non-reflectorized plate. The 3M sheeting and Flex-O-Lite plates had the same legibility about 110 ft, as a white on gray non-reflectorized plate (not shown in Figure 6). The 3M Cedit plate was the most difficult to read. The white on black non-reflectorized plate was read approximately 20 ft farther than the white on gray non-reflectorized plate.

Nighttime Legibility

Conditions similar to those for the daylight legibility test were established for nighttime legibility testing. It was found that the plates could not be read beyond a distance of approximately 100 ft and, therefore, an indoor test range was prepared. Observer data were obtained with the following plate lighting conditions:

1. Lower beam headlights only; no plate or tail lights.
2. Upper beam headlights only, no plate or tail lights.
3. Lower beam headlights with center-mounted plate lights.
4. Upper beam headlights with center-mounted plate lights.
5. Lower beam headlights with side-mounted plate lights.
6. Upper beam headlights with side-mounted plate lights.
7. Center-mounted plate lights only; no headlights.
8. Side-mounted plate lights only; no headlights.

Legibility Results

Legibility of all plates was better under daylight illumination than under any headlight or combination of headlight and plate light illumination.

Figure 6 shows that plates with a reflectorized background of 3M sheeting, plates with a reflectorized background of Flex-O-Lite beaded paint, and plates with a Flex-O-Lite reflectorized legend had nearly the same legibility distance (105 ft) for all plate lighting conditions in combination with upper beam headlighting. Non-reflectorized white on black plates were read at approximately 95 ft and white on gray at approximately 80 ft under the same upper beam conditions.

Under those conditions of trying to read the rear plates on a vehicle without lighted plate lights it would be possible to read reflectorized plates approximately 15 ft farther (105 ft) with upper beam headlights than with lower beams (90 ft) as shown in Figure 6.

Reflectorized plates with the exception of plates made with 3M's Codit showed the greatest advantage of reflectorization under the lighting condition of lower beam headlights and no plate lights.

Without the assistance of headlights but using plate light illumination the non-reflectorized plate maintained the best legibility of all plates (Fig. 7).

Legibility Summary

In considering those lighting conditions which are most often encountered when reading a plate is necessary, daylight illumination, plate light illumination, and lower beam headlight along with plate light illumination, the observer data ranked performance of the various plates (Fig. 7) as follows:

- First: The non-reflectorized white on black plate, because it was best for two of the three lighting conditions.
- Second: The reflectorized legend plate because it was best for one of the three lighting conditions.
- Third: The non-reflectorized legend on a reflectorized background plate because they were never best and because of the following observation.

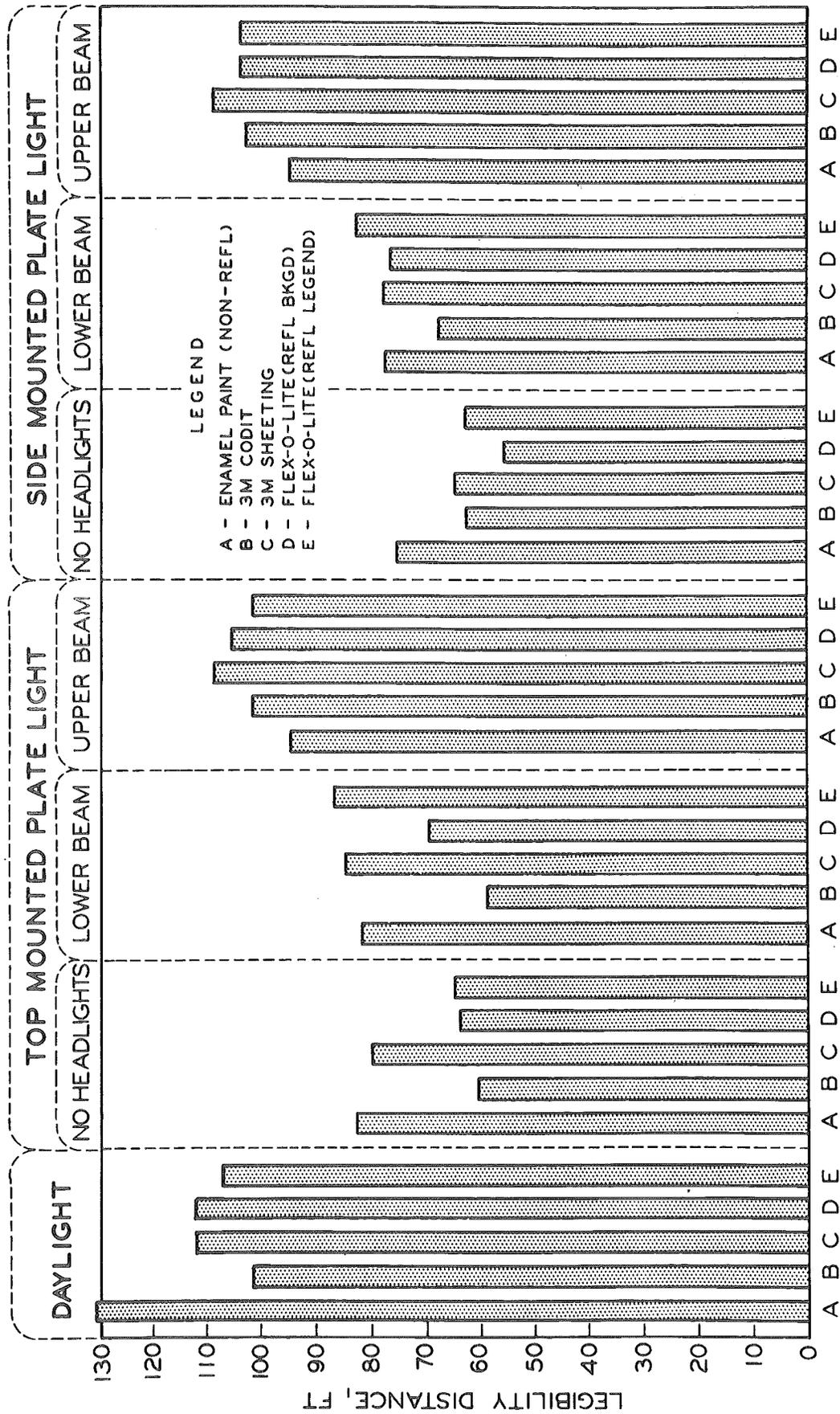


Figure 7. Effect of plate light illumination on legibility.

Consider that a white non-reflectorized legend appears gray to the eye under headlight illumination. The daytime gold color background is reflectorized and is designed to appear white or a very light yellow at night under the reflex viewing with headlight illumination. Contrast is sufficient for legibility at the greatest distance the plate can be read but as the driver approaches the plate at night, the gray legend fades to white because of the increased illumination from the headlights. The background during this approach maintains its white reflex appearance and therefore, contrast is lost. This effect is shown in Figure 8, where plates (DDK 020, PDK 202, and KNN 229 white non-reflectorized legend on a gold reflectorized background) under headlight illumination and at a distance of 100 ft (simulating legibility distance) have a legend which appears gray and background which appears white. Then, in Figure 9, (plates KVP 920, DDK 020 and KNN 229) under the same viewing conditions but at a distance of 20 ft, the legend is almost as light as the background.

In comparison a white reflectorized legend remains white under headlight illumination and the background remains dark.

Previous studies have shown that white or light letters on a dark background are more legible than black letters on a light background (1). This is also supported by the SAE in their Standard J 587b.

REGISTRATION PLATE VISIBILITY

Dynamic Visibility

Following the legibility test, the plates were used for visibility tests on the recently opened I 496 west of Waverly Rd, a suburban area of Lansing. The plates were mounted on cardboard boxes which were stationed 5 ft from the edge of the traffic lane. Additional objects such as a slow moving vehicle marker, a set of emergency reflex reflectors conforming to the minima of SAE specification J 774, and the bumper assembly were also stationed on the bituminous shoulder. Roadway delineation and highway signing in the area provided background or task interference. An observer car was fitted with a 5th wheel. Driver-observers were requested to drive through the test area at 60 mph and announce first sighting of evidence of roadside vehicles. Observers were acquainted with the plates and objects to be seen prior to actual test. Accompanying data recorders noted 5th wheel odometer readings at first sighting and also when the observer passed the test object. Seventeen observers were used.

Results

Figure 10 shows the average visibility distance of each object under upper beam and lower beam illumination. It can be seen that the emergency reflectors and the slow moving vehicle markers are visible under upper beam and lower beam illumination at distances greater than 1,500 ft. The plates with daylight gold color reflectorized backgrounds and the unlighted tail lights were visible under upper beam illumination at distances greater than 1,000 ft, but only the Flex-O-Lite reflectorized background plate and the unlighted tail lights were visible at distances greater than 1,000 ft under lower beam illumination. A plate made with Cataphote's Alert, Flex-O-Lite's reflectorized legend plate, and the rear bumper were visible at distances greater than 500 ft under both upper beam and lower beam illumination.

Visibility vs. Stopping Distances

If the suggested 550 ft stopping distance becomes the criterion for establishing the visibility distance requirement for reflectorized plates, it can be seen in Figure 10 that all of the reflectorized objects as illuminated with lower beam headlights would meet the requirement. However, the 550 ft distance is the AASHO (2) minimum stopping sight distance on wet pavement for a roadway design speed of 65 mph. The assumed vehicle speed is 55 mph. When we consider a worse condition, an actual 70 mph vehicle speed on a wet (coefficient of friction 0.25) 3-percent downgrade pavement the stopping sight distance according to AASHO becomes 1,000 ft. With the 1,000 ft stopping distance as a criterion for visibility distance it can be seen that none of the reflectorized plates except Flex-O-Lite's reflectorized background plate would meet the requirement. We should note that in comparing stopping distance with visibility distance one assumes that since a plate is visible, for example, at 1,000 ft, a driver travelling at 70 mph would see the plate and be able to stop within that distance. This assumption may be questioned for a number of reasons. One area of question arises from the method of obtaining visibility distances. Observers were specifically looking for stopped vehicle indications and therefore, greater than normally experienced visibility distances were obtained.

A bias of this nature does not render visibility test data useless because future testing of plates for conformance with any proposed visibility requirements will carry a similar bias. However, the fact that a bias would be included in a visibility requirement shows that such visibility requirements are simply an index, related to a driver's actual need. Therefore, we can reasonably make comparisons of visibility distances within

the emergency reflector at approximately 1,900 ft under lower beam headlights.

Harkness (3) investigated a triangular shaped red reflective device for slow moving vehicles and established an 880-ft identification distance criterion. Since identification of an object is more difficult than determining the presence of an object (visibility) the device should be visible at a distance greater than 880 ft. In this study the device was visible at 1,720 ft under lower beam headlight illumination.

It appears, then, that the visibility distances of the safety devices used in this study are designed to be visible at distances of at least 1,000 ft. Actual visibility distances were considerably greater than 1,000 ft. Since lifetime performance must be considered as a factor in establishing the requirements of a safety device, it appears reasonable that in order to consider reflectorized registration plates as effective safety devices, they should be visible at 1,500 ft under lower beam headlight illumination. This distance recommendation is also supported when one considers that reflectorized light from registration plates does not convey the warning message and therefore reaction times of at least 5-6 seconds can be expected. The AASHO (2) data are based on 2.5 second reaction times.

Static Visibility Test

Since the dynamic visibility test simply required an observer to detect an object while maintaining a suggested speed, a static test was conducted which required the observer to identify the object after detection.

The observer was seated in the front seat of a car next to the driver and was shown 7 test objects, from a starting distance of about 5,000 ft. Only upper beam headlight illumination was used. The objects as listed below were mounted 16 inches above the ground against a black background directly in the observer car's approach path. Observers were told when an object might appear and were given 10 seconds to detect or identify the object. The observer was asked to state if he could detect a light as each of the objects were displayed at the 5,000-ft distance and then again as the car was moved 265 ft nearer. This was repeated at 265 foot intervals until

the objects were detected and finally identified. The objects consisted of:

1. 3M sheeting registration plate.
2. Flex-O-Lite registration plate with reflectorized background.
3. 3M Codit registration plate.
4. Flex-O-Lite registration plate with reflectorized legend.
5. White on gray non-reflectorized registration plate.
6. Yellow 3-inch center-mount reflector button.
7. Yellow 12-inch diamond of highway sign grade reflective sheeting.

The distances at which reflectorized objects could be recognized under static conditions and with upper beam headlight illumination are shown in Figure 11. Time was not available to obtain lower beam data but the difference between upper beam and lower beam visibility distance noted in the dynamic study were considered applicable to the static test. Lower beam recognition distances therefore, would be approximately 200 ft less than those shown for upper beams. Observer data in this test may be extremely biased because the observer had only one task--recognize the object; also the observer was not moving (data were recorded at approximately 265 ft intervals) and the observer had little or no visual field interference or distractions. Comparison of the dynamic test results with the static test results showed that the reflectorized objects under static conditions were visible from 350 to 850 ft farther than under dynamic conditions. It should be noted however, that these greater distances are within two or three viewing increments of 265 ft.

SUMMARY

The results of this study are summarized by considering first the results of durability tests and then the results of legibility and visibility tests.

It should be noted again that the results are applicable only to those materials prepared as described earlier in this report.

Durability tests are summarized in Table 8 which shows the test and the material performance ratings, with the best performing material listed on the left and the poorest on the right.

It should be noted that enamel paint performed as well as the best reflectorized material in the weathering and salt spray corrosion tests.

The tests performed in this study did not clearly differentiate one-year and multi-year durability materials.

Legibility tests showed that under those lighting conditions which are most often encountered when reading a plate is necessary, a non-reflectorized white legend on black background plate and a reflectorized legend plate were the best. The non-reflectorized white on black plate was read at the greatest distances under daylight and plate light illumination conditions. While the reflectorized legend plate was read at the greatest distances under the combined illumination from lower beam headlights and plate lights. As mentioned earlier, plates with a white non-reflectorized legend on a gold reflectorized background show the poorest legibility performance because at night the gray appearing legend can easily blend into the background color.

Visibility tests, performed at 60 mph, showed that an emergency reflector as specified by SAE and the slow-moving vehicle marker are considerably more visible than any of the reflectorized registration plates.

The most visible plate was a Flex-O-Lite plate with a reflectorized background. The plate was visible at 1,140 ft when illuminated with lower beam headlights, only 90 ft farther than unlighted reflectorized tail lights. None of the other reflectorized registration plate materials were visible at 1,000 ft when illuminated with lower beam headlights. Plates with reflectorized legend only, were visible at 640 ft when illuminated with lower beam headlights. The Flex-O-Lite bead reflectorized background plate is the only plate which satisfies the 70 mph sight stopping distance of 1,000 ft.

Static tests, in which observers had 10 seconds to respond, showed that the Flex-O-Lite reflectorized background plate and the 3M sheeting plate were visible at an equal distance but the 3M plate was identified at a greater distance.

to insure legibility performance of registration plates primarily in the daytime. Provision was also made to obtain nighttime legibility by requiring plate lighting. Michigan's plates in the past have usually had high contrast color combinations which not only satisfy the intent of the law but also conform essentially with SAE recommendations and various legibility study recommendations of white letters on a black background. Now, the legibility function of a plate has been supplemented by legislative action requiring reflectorized plates to be a safety device. Visibility necessarily became an additional plate function. Color combinations to support this added function require a dark legend on a light colored reflectorized background, according to R. H. Wortman (4). Wortman indicated that the dark background colors lose their identification capability from dirt accumulation but the loss of identification capabilities also indicates that the available red, green and blue reflectorized colors, had a relatively low initial specific luminance. The necessity of light colors on a safety device tends to violate the experience training of drivers who have become well accustomed to reds, chrome yellows and blues as safety colors. These same light colors when reflectorized may also be in violation of Michigan's Motor Vehicle Code which requires that reflectors on the back of a vehicle be red in color.

RECOMMENDATIONS

Recommendations have been prepared which can be used as criteria for specifying adequate life of reflectorized materials and for establishing effective reflectorization. The recommendations are as follows:

1. Durability

In consideration of the premise that reflective registration plates are a safety device which may protect the motorist by increasing nighttime vehicle visibility, it would appear warranted that this protection be renewed as needed to provide adequate legibility, visibility, and safety. This renewal is probably most important for the more poorly visible vehicles, such as the older vehicles, the damaged, the rusted, or dirty vehicles.

A 400-hour artificial weathering exposure is recommended and reflectorized materials should retain 80 percent of original specific intensity at the end of the exposure. Other durability tests as specified by the Department of Administration specifications should be retained but conformance

REFERENCES

1. Janson, M. H., Smith, G. M. et al, "Requisite Luminance for Illuminated Signs." Highway Research Record No. 179.
2. "A Policy on Geometric Design of Rural Highways - 1965," Washington D. C., AASHO, 1966.
3. Harkness, K. A., "Effective Approaches to Reducing Accidents Involving Slow Moving Vehicles on Highways," Ohio State University, 1964.
4. Wortman, R. H., "An Evaluation of Reflectorized Annual License Plate Materials," Research Report No. 2, University of Illinois, May 1968.

APPENDIX

In Figure 1 photographs A, B, C & D show 3M sheeting plate, 30B, which was used in the series 2 weathering tests. The change from daylight 1A to nighttime 1B appearance is very apparent. Little weathering effect was evident at 200 hours (1A) but at 800 hours, photos Figure 1C and 1D show surface cracking and checking. Corrosion creepage can be seen in the daylight but the extent of the creepage is most obvious in the nighttime photo in Figure 1D.

Figure 2 shows 3M's white sheeting designated as one-year durability. Many of the effects showing obviously in the 800 hour photographs 2C and 2D were evident to a lesser degree at the end of 400 hours of weathering.

The Flex-O-Lite plate 36B shown in Figure 3 also shows the effects of daylight and nighttime illumination conditions. The white reflectorized legend remains white at night and the gold enamel paint background becomes very dark. Corrosion effects are obvious as the dark areas on the white legend in Figure 3D.

Figure 4 shows Flex-O-Lite's plates 37B having a reflectorized background. Again the daylight to nighttime appearance change is obvious. Corrosion exposure and weathering had very little effect on this plate, however, losses about the perimeter of the plate are evident.

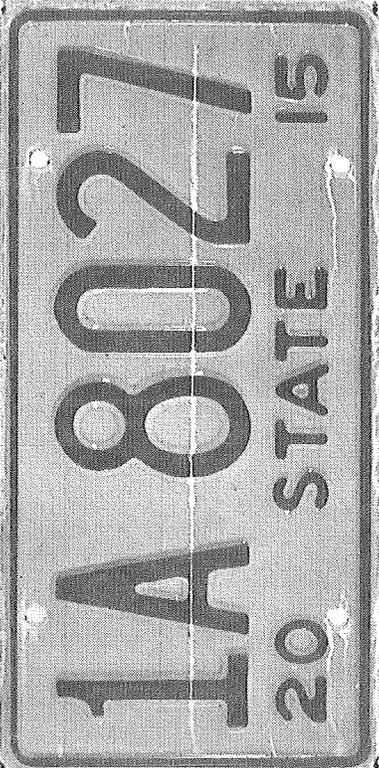
Figure 5 shows the plate made with Prismo materials by Prison Industries. The plate had a rough surface appearance initially and showed little effect from weathering and corrosion exposure.

A plate made from 3M's Codit is shown in Figure 6. Weathering and corrosion had little effect but the poor uniformity of reflex performance is obvious.

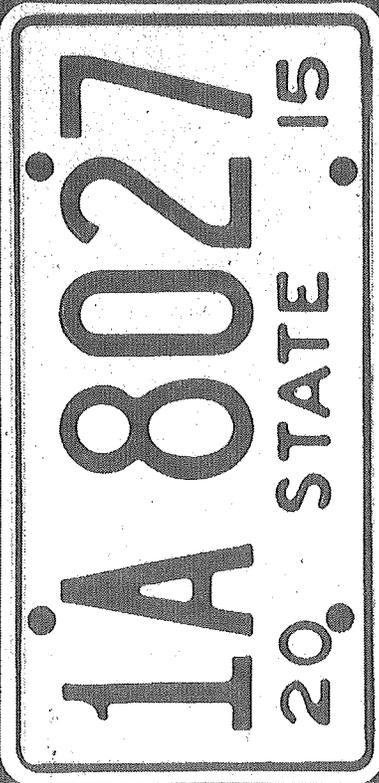
3M SHEETING PLATES

DAYTIME - DIFFUSE LIGHTING

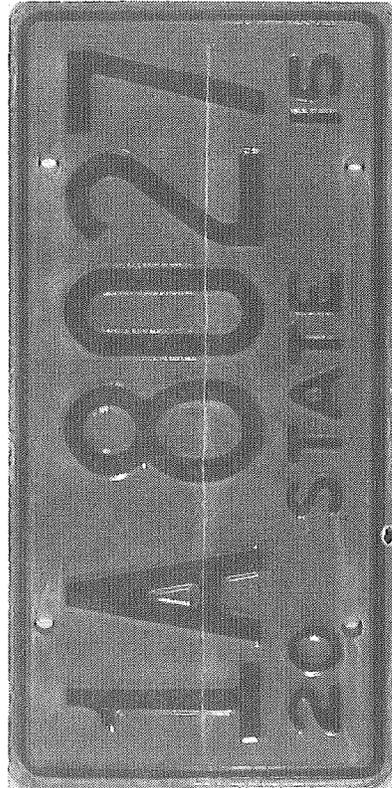
NIGHTTIME - REFLEX LIGHTING



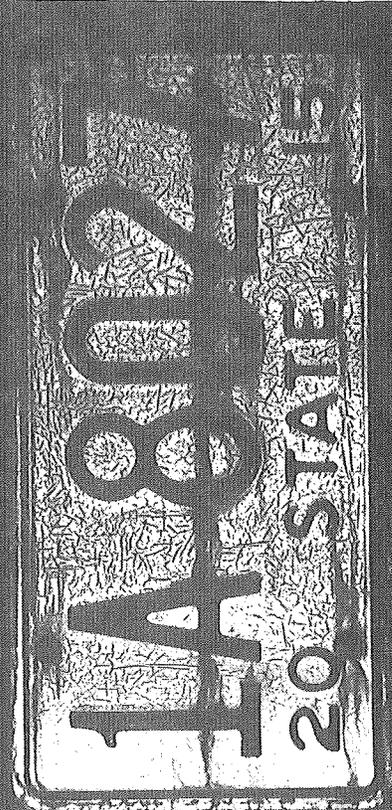
A. 200 hours Weathering - 100 hours Salt Spray



B. Appearance Prior to Testing



C. 800 hours Weathering - 200 hours Salt Spray



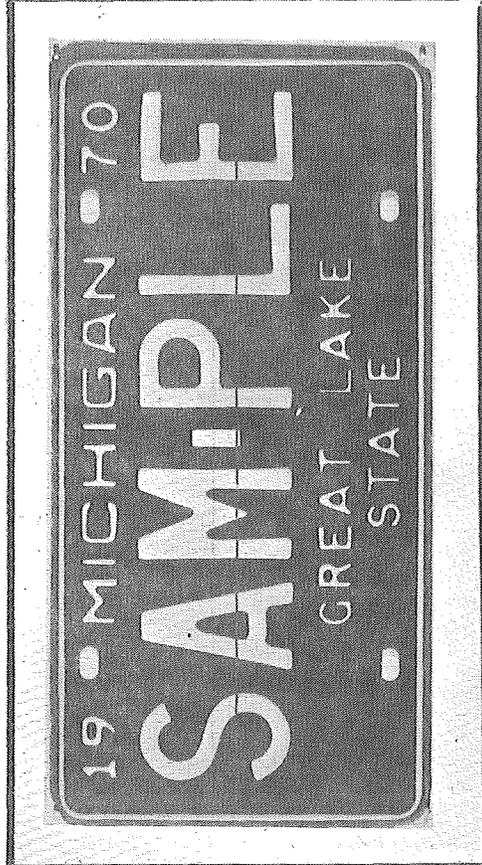
D. 800 hours Weathering - 200 hours Salt Spray

Figure 2. 3M sheeting, 1-year durability.

FLEX-O-LITE PLATES

DAYTIME - DIFFUSE LIGHTING

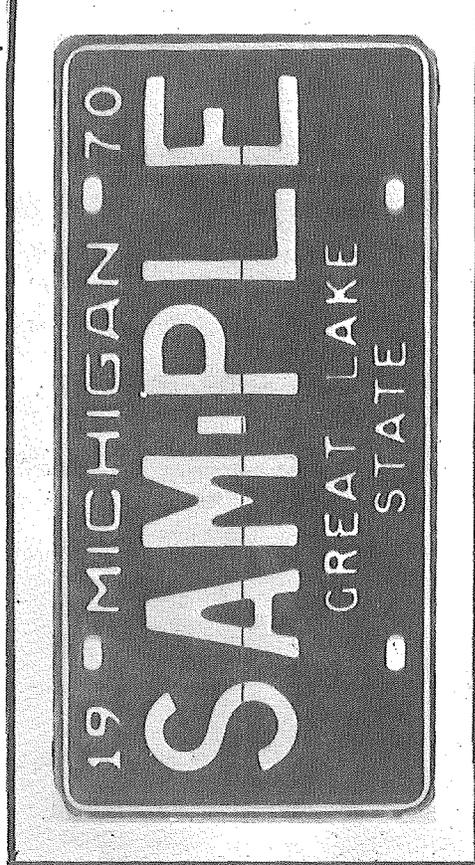
NIGHTTIME - REFLEX LIGHTING



A. 200 hours Weathering - 100 hours Salt Spray



B. Appearance Prior to Testing



C. 800 hours Weathering - 200 hours Salt Spray

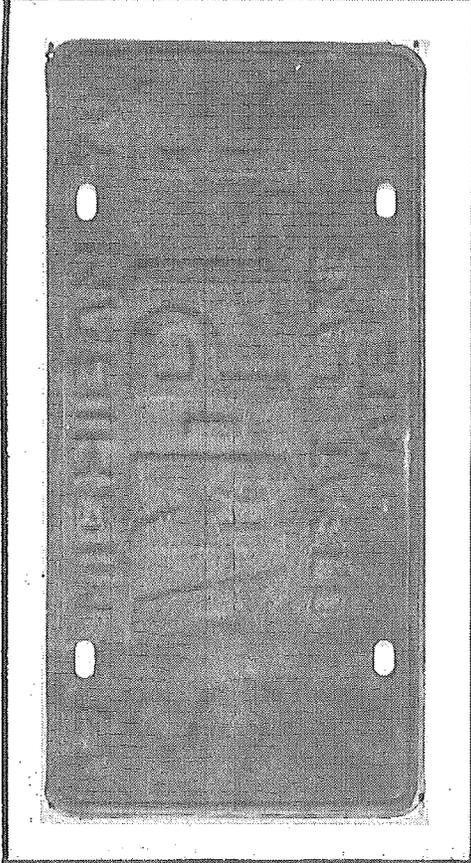


D. 800 hours Weathering - 200 hours Salt Spray

Figure 4. Flex-O-Lite, unknown durability.

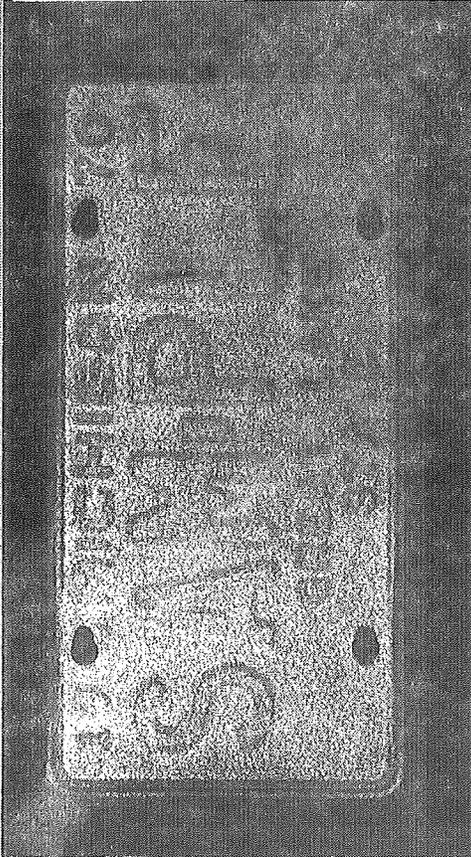
3M CODIT PLATES

DAYTIME - DIFFUSE LIGHTING

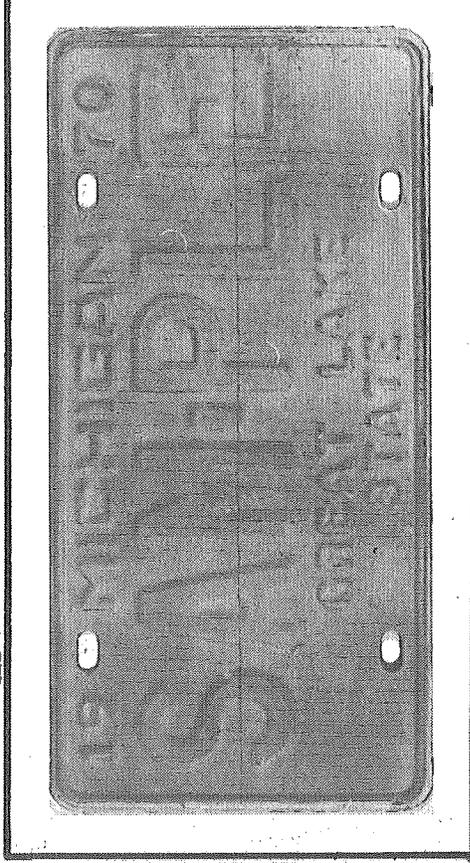


A. 200 hours Weathering - 100 hours Salt Spray

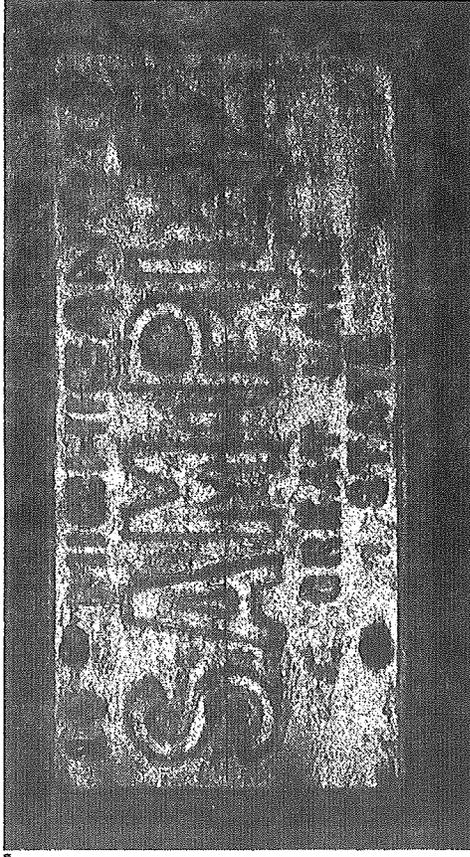
NIGHTTIME - REFLEX LIGHTING



B. Appearance Prior to Testing



C. 800 hours Weathering - 200 hours Salt Spray



D. 800 hours Weathering - 200 hours Salt Spray

Figure 6. 3M Codit.