State of California
Department of Public Works
Division of Highways

A REPORT ON COMPARISON TESTS OF REFLECTIVE MATERIALS FOR REFLECTORIZED LICENSE PLATES AS REQUESTED BY HOUSE RESOLUTION NO. 52 IN THE 1966 FIRST EXTRAORDINARY SESSION OF THE LEGISLATURE

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

January 4, 1967

House Resolution No. 52
1966 First Extraordinary Session

Mr. John Erreca
Director of Public Works

Transmitted herewith is a Report on Comparison Tests of Reflective Materials for Reflectorized License Plates pursuant to House Resolution No. 52, 1966 First Extraordinary Session.

J. C. WOMACK
State Highway Engineer

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1966 First Extraordinary Session

HOUSE RESOLUTION NO. 52

Relative to Tests by Division of Highways of Reflectorized License Plates

Resolved by the Assembly of the State of California, That the Division of Highways, Department of Public Works, is requested to conduct tests on the use of reflective license plates and to report its findings and recommendations to the Assembly on or before the fifth legislative day of the 1967 Regular Session of the Legislature.

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I. BACKGROUND - INTRODUCTION

In 1966 the Assembly of the State of California passed House Resolution No. 52 requesting the Division of Highways to "conduct tests on the use of reflectorized license plates and to report its findings and recommendations to the Assembly". This was interpreted to mean that the California Division of Highways was directed to investigate the durability, visibility, and legibility of reflective and nonreflective license plates as presently designed. It was further interpreted that no attempt need be made to determine their effect on highway safety or law enforcement.

Correspondence was immediately initiated with all State agencies concerned (the Department of Motor Vehicles, the California Highway Patrol, and the Department of Corrections) in order to establish testing parameters for color, reflectorization, and other design criteria. After developing test parameters and determining the types of materials to be considered, letters were sent to all known manufacturers of applicable reflective materials informing them of the study and inviting their participation (see Exhibit 1). Of the six manufacturers contacted, only two expressed a desire to participate in the study.

The manufacturers contacted and their replies are listed below:

1. Avery Products Corporation.

   Unable to furnish samples (see Exhibit 2).

2. Cataphote Corporation.

   Not interested (see Exhibit 3).

3. Flex-O-Lite Mfg. Corporation.

   Will participate (see Exhibit 4).

4. Hawkins-Hawkins Co., Inc.

   Unable to furnish samples (see Exhibit 5).

5. Minnesota Mining & Mfg. Co.

   Will participate (see Exhibit 6).

6. Prismo Safety Corp.

   Not interested (see Exhibits 7 and 8).

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This report presents the results of physical tests and visual, and photographic evaluations performed by the California Division of Highways, Materials and Research Department, on the license plate samples submitted by the two participating reflective products manufacturers.

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II. OBJECTIVES

The primary objective of this investigation was to test and evaluate the various reflective materials currently available for use in the design and manufacture of reflectorized license plates in order to determine the most effective and economical material for this purpose:

A. To determine which reflective material best fulfills the physical requirements for reflective license plates.

B. To evaluate the various color combinations in reflective materials and determine which combination produces (a) the best nighttime visibility and/or (b) the best message legibility.

C. To determine the costs of the two types of reflectorized license plates as compared to the current cost for the standard nonreflectorized license plate.

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III. FINDINGS

There are two basic systems of reflectorization that are currently applicable for use in the manufacture of license plates. These systems are (1) enclosed lens reflective sheeting and (2) exposed beads on a baked enamel binder.

At the present time there is only one known manufacturer capable of producing enclosed lens reflective sheeting in the sizes and quantities necessary for mass production of license plates for the State of California. Two additional manufacturers are producing nominal quantities of enclosed lens reflective sheeting but have declined to submit samples for this evaluation because of present production limitations.

Of the three major suppliers of exposed bead reflective materials, only one expressed an interest in this test program.

The 3M Co. has indicated that reflective sheeting may be satisfactorily applied to either aluminum or galvanized steel but not to the copper bearing steel currently used for the production of California license plates. Exposed beads may be satisfactorily applied to aluminum, galvanized steel or the copper bearing steel.

Both reflective systems are available in a wide variety of color combinations. However, of the two systems tested, reflective sheeting is the only material that transmits true color when viewed under reflected light at night.

The effective service life of either the exposed bead or the reflective sheeting material has not been accurately established. More than 10 years past experience by the Division of Highways in its highway signing program has indicated that there is a rapid loss of reflectance in all exposed bead systems due to the accumulation and adherence of surface dirt. Daytime legibility would also be impaired by the permanent stains caused by exhaust hydrocarbons. We have had no past experience with the grade of reflective sheeting proposed for use in license plate production, but it is significant that the manufacturer (3M Co.) of this material stresses that five years is the maximum service life that can be expected.

At the present time 28 states are using or will use reflective license plates in their 1967 issue. Twenty of these states are or will use reflective sheeting. The length of plate issue will vary from one to five years. From the available data we found no state with more than four years of in-service experience with a single issue of enclosed lens reflective sheeting license plates.

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The following findings are based on an analysis of the results of the physical tests and the visual and photographic observations performed in this investigation, supplemented by the significant findings of other researchers.

A. Physical Requirements.

1. In the paint adherence test employed, the standard baked enamel and the exposed bead specimens exhibited no distress. All license plate reflective sheeting samples delaminated, either within the structure of the sheeting or between the sheeting and the screening paste. Although it is doubtful that in-service license plates in California would be subjected to prolonged moisture exposure such as is simulated by this test, these results are of enough concern to limit the estimated average effective service life of the reflective sheeting system on license plates to four years, until further experience is gained with this material.

2. In the abrasion test employed, both the exposed bead and the reflective sheeting systems showed greater resistance to a medium abrasive material than did the standard baked enamel. The exposed bead system exhibited the highest resistance to this abrasion.

3. The legend paints of all the license plates tested exhibited equal abrasion resistance.

4. After 200 hours of exposure time in the Fadeometer, none of the reflective license plate specimens or the standard nonreflective sample show any signs of fading or discoloration.

5. Reflective sheeting exhibited the highest resistance to sandblasting. The standard baked enamel samples exhibited a lower resistance and the exposed bead samples exhibited the least resistance to sandblasting.

6. The reflective sheeting and exposed bead samples were more susceptible to soiling than the standard baked enamel license plates. The exposed bead samples were difficult to clean and showed greater loss of reflectance after ordinary cleaning. After a steam car wash, the reflectance of the exposed bead sample was only restored to 67% of original whereas the reflectance of the reflective sheeting was restored to 89% of the original reflectance. It is estimated that the average effective reflective service life of the exposed bead system on a license plate is about 2 years due to soiling and staining.

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7. After 322 hours of corrosion testing in acetic acid-salt spray, the reflective sheeting on aluminum and the exposed beads on copper bearing steel showed less evidence of corrosion than the standard baked enamel license plate. Reflective sheeting on galvanized steel and on copper bearing steel showed more evidence of corrosion than did the baked enamel specimen. However, all of the materials tested will resist damaging corrosion for more than four years.

B. Visibility.

1. Reflective sheeting license plates exhibited the highest reflectance values in all color combinations tested. The highest total reflectance value was exhibited by the reflective sheeting samples with a green or blue reflective legend and a white reflective background.

2. License plates with reflectorized white backgrounds are clearly visible at night at a distance of 600 feet. This is the highway design stopping sight distance for a vehicle traveling 70 miles per hour.

3. The reflectorized background license plates clearly indicated the position of an approaching "one-eyed" vehicle.

C. Legibility.

1. Reflective license plates, on the average, are 28% more legible at night than a nonreflective plate[2]. Due to the character size on the California license plate, none of the reflectorized plates tested were legible at a distance greater than 150 feet. At this distance the comparative brightness of the two types of reflective materials tested is not as important as character size.

2. All reflectorized license plates tested were legible at a distance of 75 feet when viewed against the high beam headlights of an oncoming vehicle.

3. Considering the present California license plate design (character height, width, spacing, and

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stroke width), the most legible reflective plate is obtained with a color combination comprised of a white reflective legend on a black, nonreflective background.

4. Based upon research performed by others[2], the difference in nighttime legibility between the reflective plate color combinations tested in this study is less than 13%.

5. Reflective sheeting and exposed bead license plates are both legible, under reflected or incident light (daylight), at angles up to 60 degrees when viewed at a distance of 50 feet.

D. Cost.

1. The current cost of the standard nonreflectorized baked enamel on steel license plate is $0.22 per pair and its estimated average service life is in excess of 10 years. The estimated cost of the steel reflective sheeting plates is $0.78 per pair. The estimated cost of the aluminum reflective sheeting plates is $0.84 per pair. The estimated service life of the reflective sheeting is about 4 years. The estimated cost of the exposed beads (only legend reflectorized) on steel plate is $0.27 per pair. The estimated cost of the exposed bead (only background reflectorized) on steel plate is $0.36 per pair. The estimated service life of the exposed bead system is in excess of 4 years. However, from past experience with the exposed bead system used in California's highway signing, there is a substantial loss in reflectance and daytime legibility in one to two years due to the adherence of surface dirt and permanent staining of the binder enamel.

2. The estimated cost per plate per year for a ten year period is as follows:

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ESTIMATED COST PER PLATE PER YEAR FOR A TEN YEAR PERIOD

Type of Plate	Substrate	Area Reflectorized	Cost of Each Plate	Estimated Effective Service Life	Estimated Total Ten Year Cost Per Plate	Estimated Cost/Plate/ Year for Ten Years
Nonreflective Baked Enamel	Steel	None	$0.11	10 years	$0.11	$0.011
Enclosed Lens Reflective Sheeting	Galvanized	Background, Legend Or Both	$0.39	4 years	$0.975	$0.0975
	Aluminum	Background, Legend Or Both	$0.42	4 years	$1.05	$0.105
Exposed Beads	Steel	Background	$0.18	2 years	$0.90	$0.090
		Legend	$0.135	2 years	$0.675	$0.0675
	Aluminum	Background	$0.20	2 years	$1.00	$0.1000
		Legend	$0.155	2 years	$0.775	$0.0775

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IV. RECOMMENDATIONS

1. If increased nighttime legibility of California license plates is considered necessary, the legend or background of the plates should be reflectorized.

2. If increased nighttime visibility (target value) in California license plates is considered necessary, the plates should have a reflectorized background.

3. If a license plate service life greater than 4 years is desired, the plate cannot be reflectorized since this exceeds the estimated effective life of the various reflective systems.

4. If a reflective license plate service life up to four years is desired, all factors considered, it is recommended that the enclosed lens reflective sheeting system be employed. For optimum nighttime visibility as well as excellent legibility, the background should be reflective white or yellow. The legend can be an opaque dark color. If a reflective legend is desired, in addition to the reflective background, the background must be reflective white. The metal substrate can be either aluminum or galvanized steel.

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V. DISCUSSION

On the national average, one third of all night traffic accidents are directly related to reduced visibility[3]. Rear-end type collisions account for a large portion of these accidents. Thirty eight percent of all nighttime injury accidents in California during 1965 were rear-end collisions. In an attempt to reduce the number of rear-end accidents, reflectorized license plates are being used or have been adopted for use in 1967 in twenty-eight states. The primary objective of a majority of these states' safety program has been to equip each registered vehicle with a reflectorized license plate with high nighttime visibility or target value that would serve as a warning to other vehicles approaching them at night. This warning target would be of particular value in distinguishing parked or stalled vehicles with their lights off, vehicles with poor or faulty tail lights, and/or tail light reflectors, and to delineate the relative position of an approaching "one-eyed" vehicle. Of secondary consideration, but considered equally important by some law enforcement agencies, is the value of increased nighttime legibility of the license plate as a result of the reflectorization.

No attempt was made in this investigation to establish the safety merits of reflective license plates or to determine which consideration (greater visibility or increased legibility) is of primary importance. However, reflective and nonreflective license plates were investigated and will be discussed relative to the various materials available, the test parameters, the test results, visibility and legibility.

A. Materials.

The two manufacturers that submitted samples for this investigation represent the two basic reflective systems that are applicable for the reflectorization of license plates. These systems are:

1. Enclosed Lens Reflective Sheeting - Minnesota Mining & Mfg. Co. - "Scotchlite".

   Enclosed lens reflective sheeting is a reflective lens system consisting of spherical lens elements partially embedded in a binder film on a precoated adhesive paper backing and encased by a translucent pigmented resin space coat which has a smooth, flat outer surface. This material is applied directly to the flat license plate substrate material in a continuous nip-roll operation. The plates are then blanked, punched and embossed or debossed depending upon whether a dark colored legend or a dark colored

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background is desired. An opaque or translucent pigmented enamel is then applied to the raised portions of the plate by a roller coating process thus delineating the message. Reflective sheeting may be applied satisfactorily to either an aluminum or galvanized steel substrate. The manufacturer of this sheeting does not recommend its application to the copper bearing steel currently being used in the manufacture of California license plates.

For added resistance to weathering the manufacturer recommends that a finishing clear-coat be applied by dipping, to all reflective sheeting license plates. From operational experience on reflective sheeting highway signs, the California Division of Highways has found that finish clear-coat deteriorates in three to five years, resulting in a considerable decrease in reflectance. For this reason, initial clear-coat has been deleted from highway signs in California.

Twenty of the states who have adopted reflective license plates have selected enclosed lens reflective sheeting. The current or planned length of issue varies from one to five years in these states as follows:

Nine states - - - - - -	one year issues
Two states - - - - - -	two year issues
Four states - - - - - -	three year issues
Two states - - - - - -	four year issues
Three states - - - - -	five year issues

The quality of the materials and the construction of the one year plates differs from the multiple year plates. From the available data we found no state that has had more than four years of actual in-service experience with a single issue of enclosed lens reflective sheeting license plates. One state, North Dakota, is in its fourth year of its second four year issue.

2. Exposed Beads on Binder - Flex-O-Lite Mfg. Co. - "Flex-O-Lite".

The exposed bead system consists of spherical lens elements which are partially embedded in a pigmented baked enamel binder. The binder can be applied by dipping or roller coating. For reflective background, beads are applied to the entire surface of the blanked, punched and embossed license plate blank. For reflectorized legend, beads are applied only to the raised surface of a blanked, punched, embossed and prepainted license plate blank. In either case, the beads are sprinkled onto the binder while it is in a

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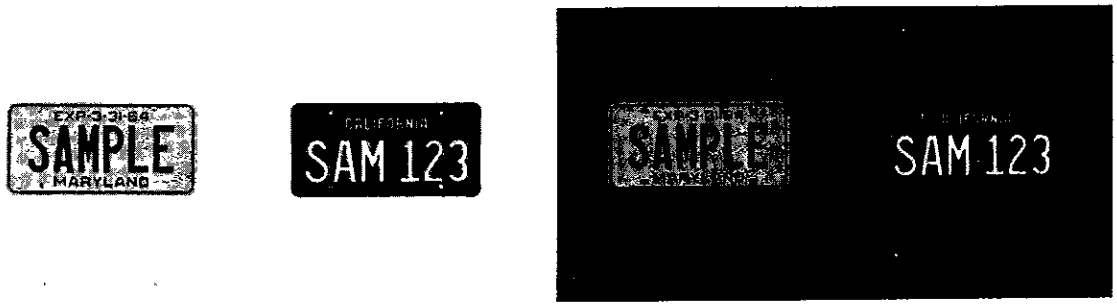
wet, tacky condition. No clear coating is necessary with the exposed bead system. This system is compatible with galvanized steel, the presently used copper bearing steel or aluminum. Essentially the only difference between the standard baked enamel plate now in use and a beaded plate is the addition of the beads to the enamel binder.

Enclosed lens reflective sheeting is the only type tested which fully transmits true color under reflected light at night and it is available in a wide range of colors. Satisfactory reflectorization is possible with exposed beads only in white and yellow. However, under reflected light at night the exposed bead yellow, that was tested, becomes washed out, presenting a cream colored appearance (Figure 1).



Incident Light Reflected Light

Figure 1

Yellow Exposed Beads on Binder

With the exposed bead system it is not possible to reflectorize both the legend and the background of a license plate (Figures 4 and 5). Reflectorization of both the legend and the background is possible with reflective sheeting by use of a translucent screening paste. (Figures 2 and 3).

B. Test Parameters.

All sample license plates used in this study were 6 inches by 12 inches with a letter height of 2-11/16 inches and a stroke width of 1/4 inch. "SAM123" was the legend on all samples except as noted.

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Listed below are the color combinations, plate designs, and reflective systems evaluated in this investigation:

1. Enclosed Lens Reflective Sheeting - Embossed (Figure 2).

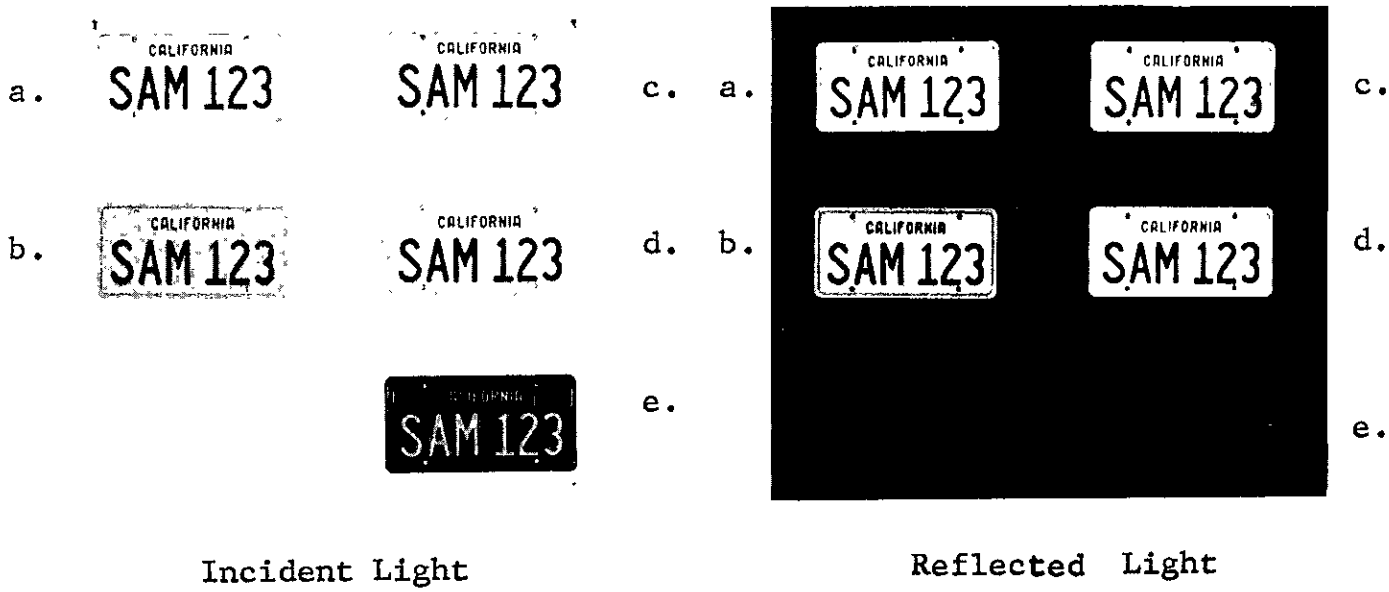

Figure 2

a. Reflective green legend - reflective white background.

b. Nonreflective black legend - reflective yellow background.

c. Reflective blue legend - reflective white background.

d. Nonreflective black legend - reflective white background.

e. Standard nonreflectorized baked enamel plate.

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2. Enclosed Lens Reflective Sheeting - Debossed* (Figure 3).

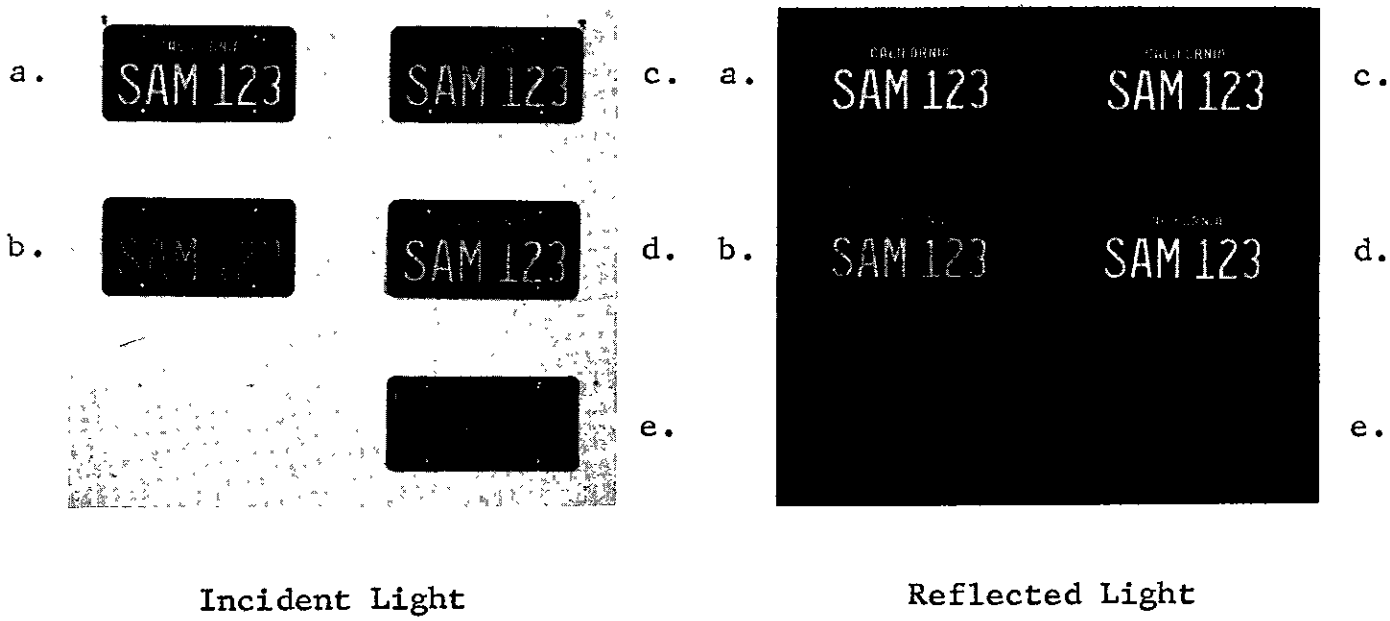

Figure 3

a. Reflective white legend - reflective green background.

b. Reflective yellow legend - nonreflective black background.

c. Reflective white legend - reflective blue background.

d. Reflective white legend - nonreflective black background.

e. Standard nonreflectorized baked enamel plate.

* NOTE: Debossing dies necessary to produce this type plate were not available; therefore, for this evaluation flat plates with reverse screened legend were utilized to simulate the appearance of a debossed license plate. In actual production practice, the reverse screening method would not be economically feasible and debossing would be necessary for these color combinations.

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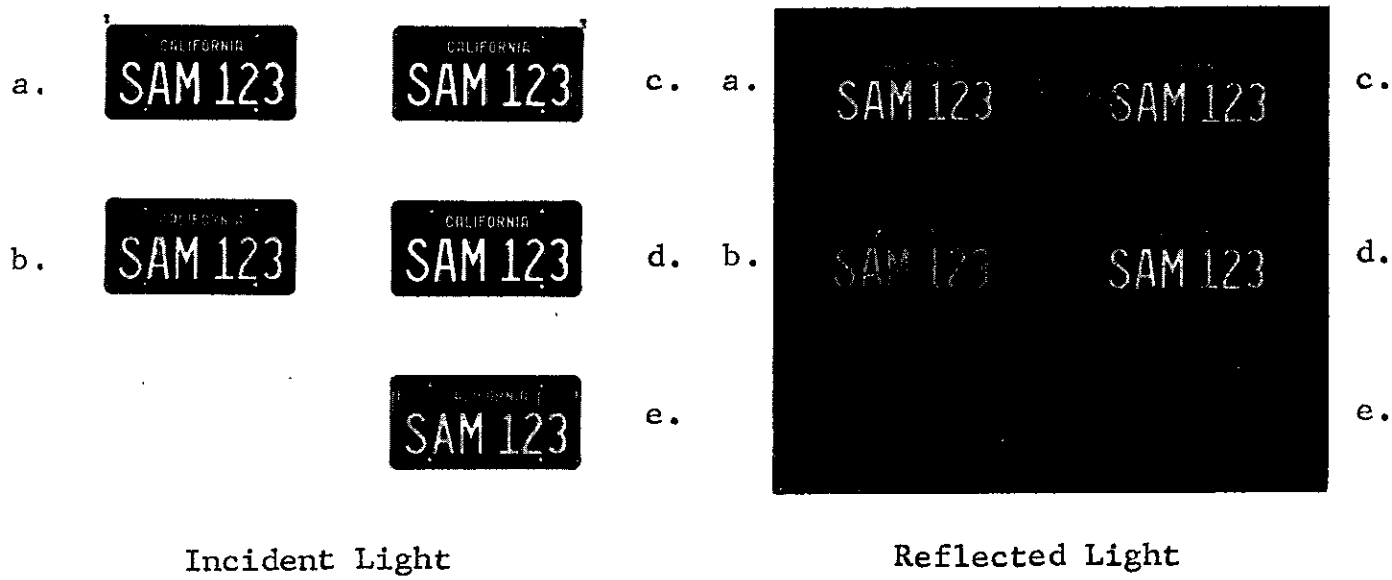
3. Exposed Beads - Embossed (Figure 4).



Incident Light

Reflected Light

Figure 4

a. Reflective white legend - nonreflective green background.

b. Reflective yellow legend - nonreflective black background.

c. Reflective white legend - nonreflective blue background.

d. Reflective white legend - nonreflective black background.

e. Standard nonreflectorized baked enamel plate.

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4. Exposed Beads - Embossed (Figure 5)

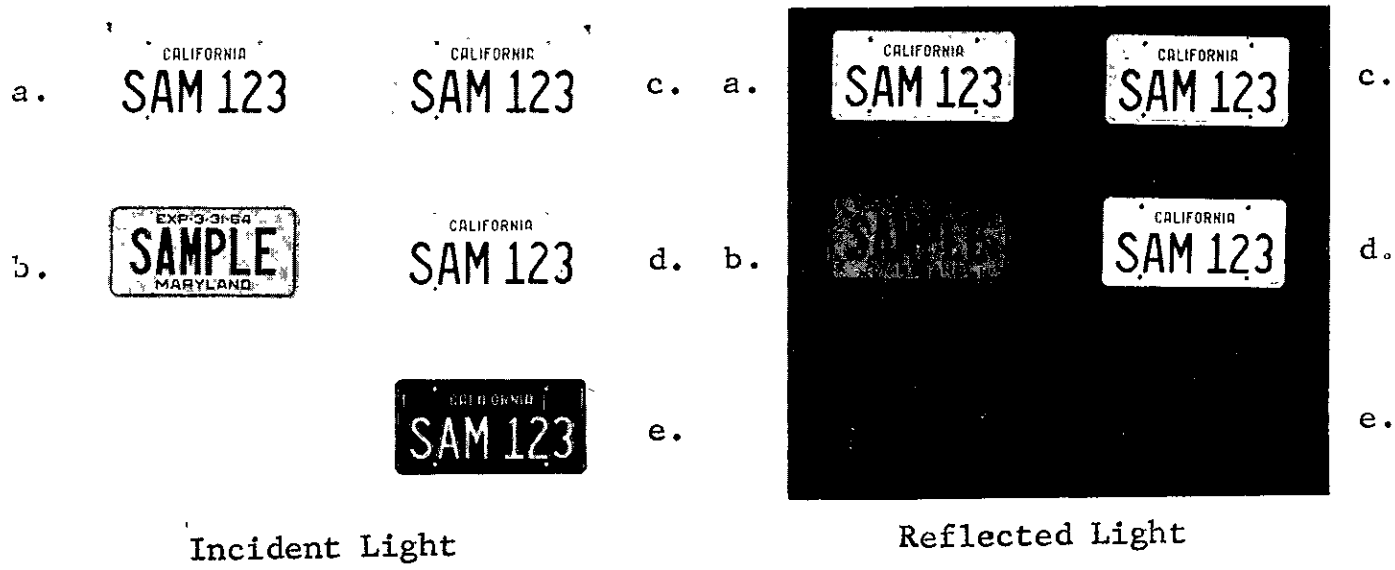

Figure 5

a. Nonreflective green legend - reflective white background.

b. Nonreflective black legend - reflective yellow background.

c. Nonreflective blue legend - reflective white background.

d. Nonreflective black legend - reflective white background.

e. Standard nonreflectorized baked enamel plate.

C. <u>Test Procedures and Results</u>.

Samples of license plates finished with exposed beads on binder, reflective sheeting and standard baked enamel were equally subjected to a series of physical and photometric tests. The series of tests included standard paint adherence, resistance to wear, and fading tests as well as special tests designed to subject the sample plates to various methods of accelerated wear and soiling. Following each test, the specimens of each type plate were inspected and photographed under both incident and reflected light and photometric reflectance measurements were made to

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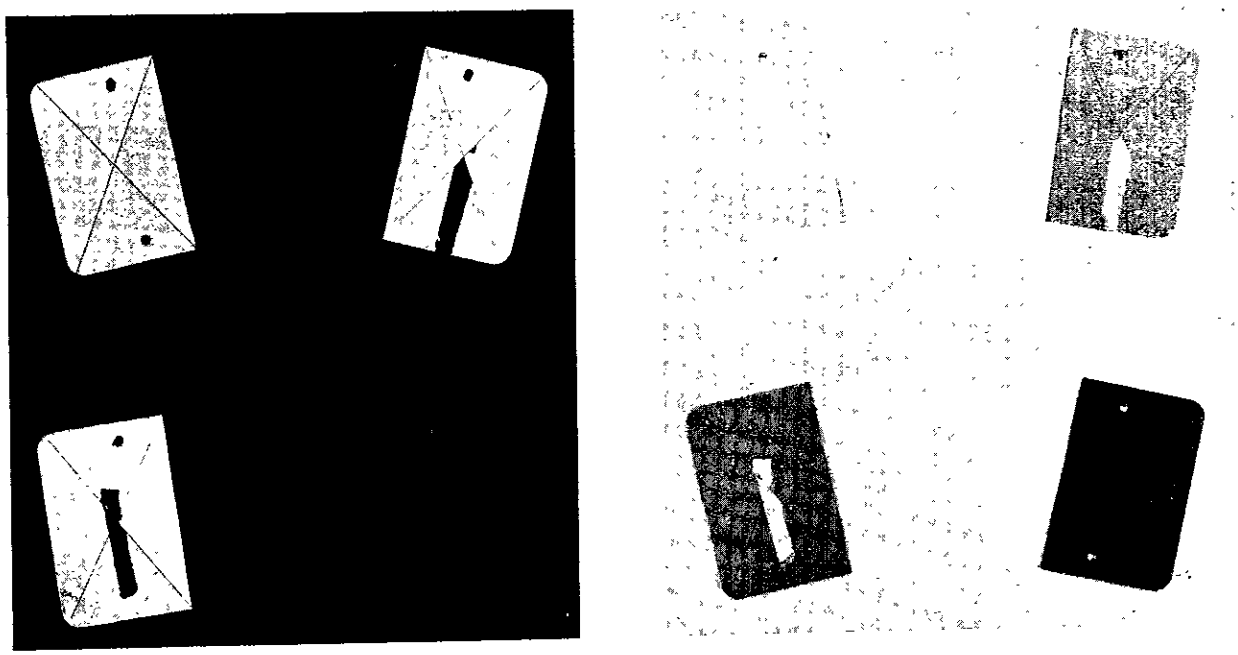
determine any variation from control samples. The evaluation procedure consisted of the following tests with results tabulated for the samples tested:

1. Paint Adherence (Test Method No. Calif. 645-A) (see Exhibit 9).

   One prepared specimen of each type plate was submerged in 95° F ± 3° distilled water for 192 hours (8 days) and then tested for adherence by applying masking tape and stripping it off.

   Both the yellow and black baked enamel specimens representing the California standard license plates showed no evidence of flaking, chipping, blistering, softening or peeling of the paint from the metal substrate. The exposed bead specimens also exhibited no distress after subjection to this test. There was evidence of delamination of the yellow and white reflective sheeting samples. This delamination occurred within the reflective sheeting structure rather than at the glue line between the sheeting and the metal substrate (Figure 6).



Reflected Light Incident Light

Figure 6

Paint Adherence Test Specimens of Background Materials.

Top row from left: white exposed beads; white reflective sheeting.

Bottom row from left: yellow reflective sheeting; standard black baked enamel.

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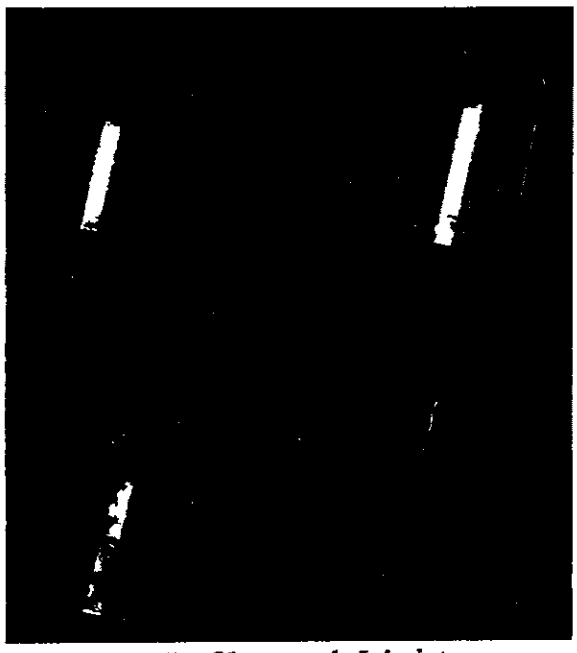
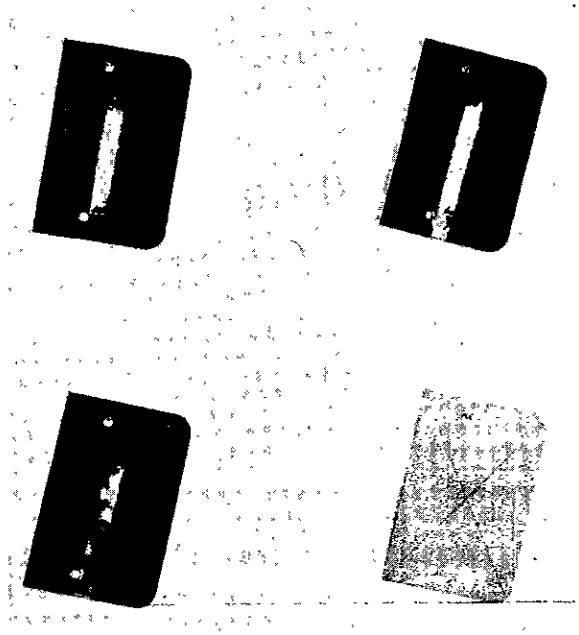
All roller coated reflective sheeting specimens (black on white, blue on white, green on white) exhibited delamination between the screening paste and the reflective sheeting (Figure 7).



Reflected Light



Incident Light

Figure 7

Paint Adherence Test Specimens
of Roller Coated Legend Materials

Top row from left: black on white - reflective sheeting; green on white - reflective sheeting.

Bottom row from left: blue on white - reflective sheeting; standard yellow on black baked enamel.

In an effort to correlate the adherence test results with a product with which we have had previous experience, specimens of yellow, white, and screened Type "Z" reflective sheeting of the type currently used for highway signs were also subjected to this same test. We understand that the Type "Z" reflective sheeting, also produced by the 3M Co. and used in highway signing, is a higher grade, longer life material than that produced for use in license plate reflectorization. However, due to the increased thickness of the "Z" type material, it is not recommended that it be embossed or debossed, thus making it unsuitable for use on license plates.

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In the test, the Type "Z" reflective sheeting specimens exhibited no failures within the reflective sheeting structure. The screened specimen did exhibit some delamination of the pigmented screening paste from the surface of the Type "Z" reflective sheeting.

The California Division of Highways has more than four years of field experience with the Type "Z" reflective sheeting as a signing material. We are not aware of any instance where delamination between the screening paste and the reflective sheeting has occurred. Delamination within the reflective sheeting structure has not been a problem, either, except in limited situations where long term sustained exposure to direct moisture occurs. For example, reflective sheeting on signs that have been completely covered with snow for prolonged periods in our mountainous areas has shown structural delamination similar to that observed with the license plate reflective sheeting test specimens.

However, it is doubtful that in-service license plates in California would be subjected to this type of prolonged concentrated moisture exposure. Nevertheless, based on the results of the tests on the laboratory license plate specimens and the field sign experience, the estimated average effective service life for enclosed lens reflective sheeting material on license plates should be limited to four years until further experience is gained with this material.

2. Abrasion Resistance (Tabor Abrader).

Prepared specimens of each type of reflective material and the standard baked enamel were subjected to abrasion revolutions by a "Tabor Abrader". The results from this test were reported as the number of revolutions required to wear through the reflective material or through the surfacing material. All specimens were subjected to abrasion with a No. CS-10 abrasive wheel under a 1000 gram load. The CS-10 abrasive wheel is a resilient, medium abrasive, rubber wheel designed to produce a mild abrading action similar to that that would be experienced during normal handling, cleaning and polishing.

The exposed bead specimens did not wear through after 1300 revolutions. It was evident that the beads on these specimens were more abrasive than the abrasion wheel used and were wearing the wheel at a faster rate than they were being abraded.

The background white and yellow reflective sheeting was abraded through to the glue line after 1000 revolutions. All roller coated reflective sheeting specimens (black

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on white, blue on white, green on white) were abraded through to the white sheeting base material after 200 revolutions.

The black background baked enamel standard license plate specimens were abraded through to the metal substrate after 400 revolutions and the yellow, roller coated specimens were abraded through to the black base coat after 200 revolutions.

An additional series of abrasion tests utilizing a No. H-22 abrasive wheel under a 500 gram load was performed on all background reflective materials (exposed beads, yellow and white reflective sheeting) and the standard black, baked enamel license plate material. The H-22 abrasive wheel is a nonresilient, vitrified wheel producing a coarse abrasive action. With this abrasive wheel all types of reflective materials were abraded through to the metal substrate after 100 revolutions. The standard black baked enamel abraded through after 35 revolutions. It should be noted here that all the abrasion results were based upon the number of revolutions required to wear through the individual coating materials. In all cases reductions in reflective ability occurred immediately upon starting the abrasive action and progressed throughout the abrasive cycle. No attempt was made to measure the loss in reflectance.

See Exhibit 10 for a complete numerical tabulation of the Abrasion Testing results.

3. Fade Resistance.

One specimen of each type and color license plate was exposed in an Atlas type FDA-RC Fadeometer. To date, the exposure time (200 hours) for each of the specimens has not been sufficient to produce any evidence of fade or discoloration. This test will be continued until significant color changes have been noted to a maximum of 1000 hours. The final results will be available at a later date.

4. Resistance to Sandblasting.

One specimen of each type plate was subjected to light sandblasting (5 seconds) and one specimen subjected to heavy sandblasting (15 seconds). In all tests the plates were mounted 10 feet from the nozzle of the sandblast appartus.

Inspection of the specimens after the tests indicated that the reflective sheeting samples exhibited the highest resistance to abrasion by sandblast, the baked

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enamel samples exhibited a far lower resistance and the beaded samples exhibited the least resistance.

When viewed under incident light, the reflective sheeting sample showed little visual evidence of damage when subjected to light sandblasting whereas the beaded sample and the baked enamel sample were visibly damaged. Heavy sandblasting obliterated the legend on both the beaded and baked enamel samples while the reflective sheeting sample, although heavily damaged, is still legible (Figure 8).

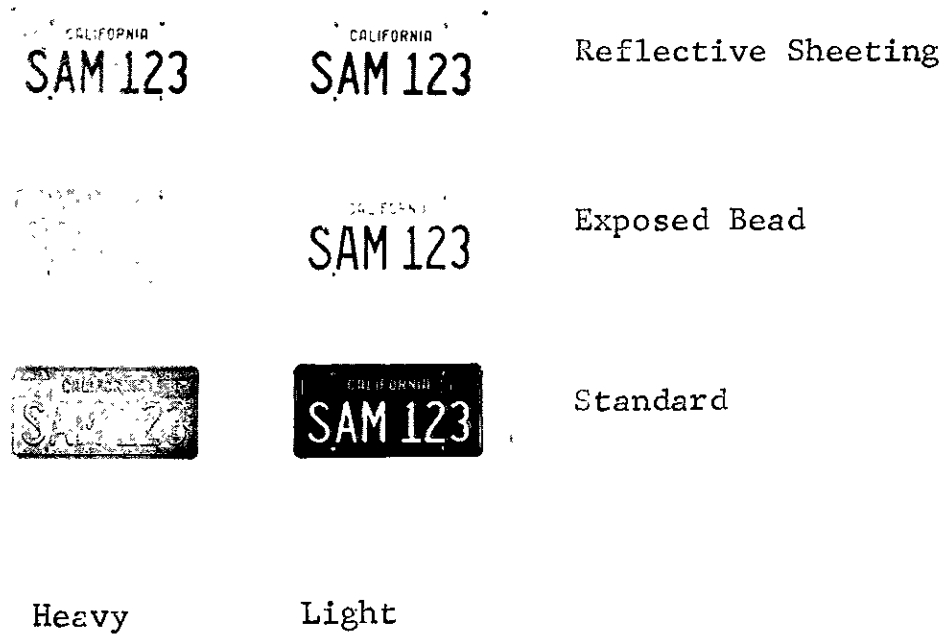

Figure 8

Sandblasted Specimens
Viewed Under Incident Light

Under reflected light, the reflective sheeting sample and the beaded sample subjected to light sandblasting sustained a reflectance loss of 49% and 73% respectively. There was a complete loss of reflectance on all samples subjected to heavy sandblasting (Figure 9).

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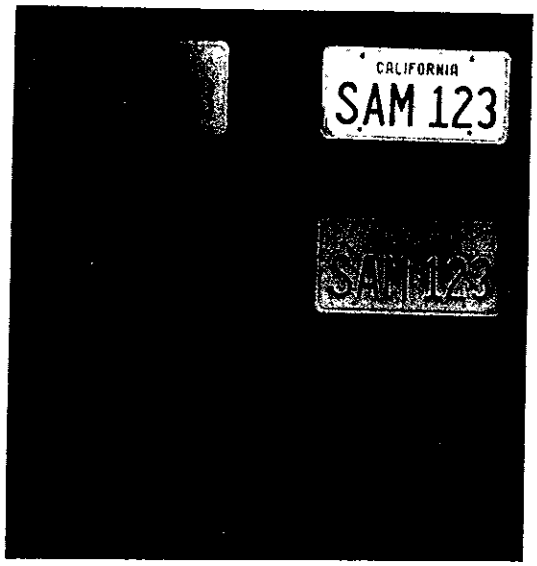

Reflective Sheeting

Exposed Bead

Standard

Heavy Light

Figure 9

Sandblasted Specimens
Viewed Under Reflected Light

Exhibit 11 is a tabulation of the before and after reflectance values of the sandblasted specimens.

5. Resistance to Soiling.

One sample of each type plate was exposed to a concentration of vehicle exhaust fumes. This was accomplished by mounting the plates on the rear bumper of a test vehicle directly above each of the two exhaust pipes. The exhaust fumes were deflected onto the plates by means of curved baffle plates (Figure 10). The purpose of this test was to expose the license plates to concentrated exhaust fumes while minimizing the accompanying heat, which it was found would scorch the reflective surfacing material.

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Figure 10

Mounting Procedure
For Resistance to Soiling Tests

The test vehicle was operated at normal speeds in a combination of city and open highway driving. Following one hour of operation the plates were switched and the vehicle operated for an additional hour. In this manner each plate was equally exposed to the vehicle's two exhaust pipes. Two samples of each type plate were exposed during this test.

Following the exposure period, photographs were taken under incident and reflected light and reflectance measurements were made to determine the reflectance loss due to the coating of unburnt hydrocarbons from the exhaust. It was noted that under incident light the baked enamel plate was the least affected by the exhaust gases. It was apparent that the black hydrocarbon deposit does not show up on the black enamel background as readily as on the white reflectorized specimens. The reflective sheeting sample exhibited the greatest degree of soiling prior to cleaning when viewed under incident light (Figure 11). Both the reflective sheeting and the exposed bead samples sustained a 90% loss in reflectance due to this soiling.

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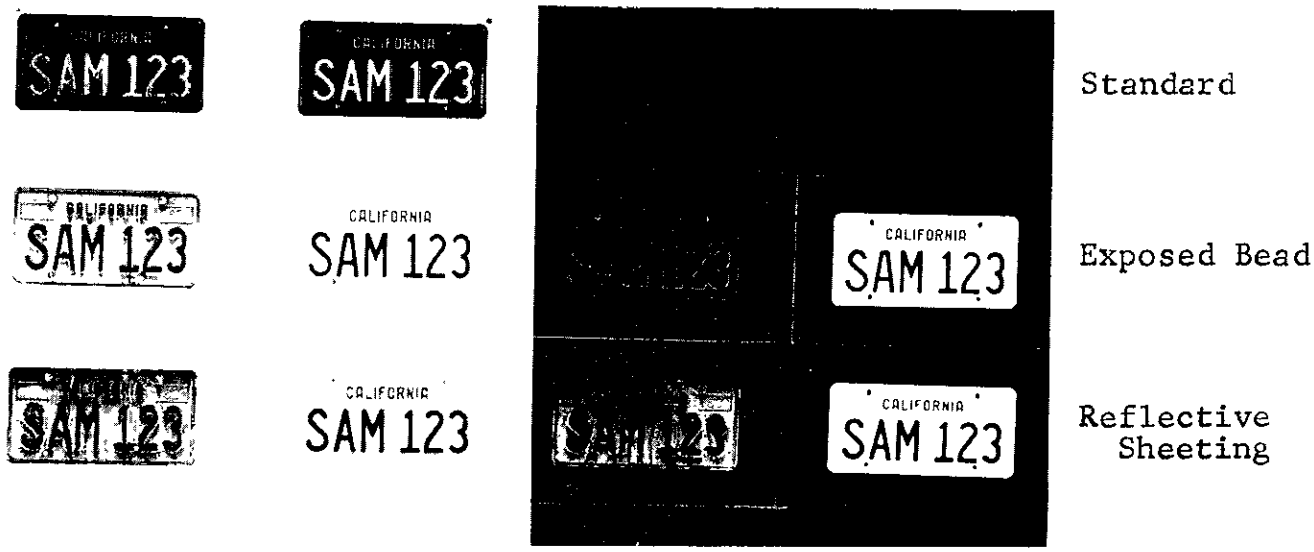

Soiled Control Soiled Control

Incident Light Reflected Light

Figure 11

Soiled Specimens
Viewed Under Incident And Reflected Light

Exhibit 12 is a tabulation of the before and after reflectance values of the soiled samples.

6. Ease of Cleaning.

Following the resistance to soiling evaluation, attempts were made to clean the soiled surfaces by means of various cleaning methods and agents.

One set of soiled plates was cleaned by scrubbing with a soft fiber brush in warm soapy water. The baked enamel and reflective sheeting samples were readily cleaned. However, it was impossible to remove all of the visible hydrocarbon residue from the beaded sample, even after repeated scrubbings (Figure 12). This harsh scrubbing removed a portion of the opaque legend material allowing the reflective white background to show through.

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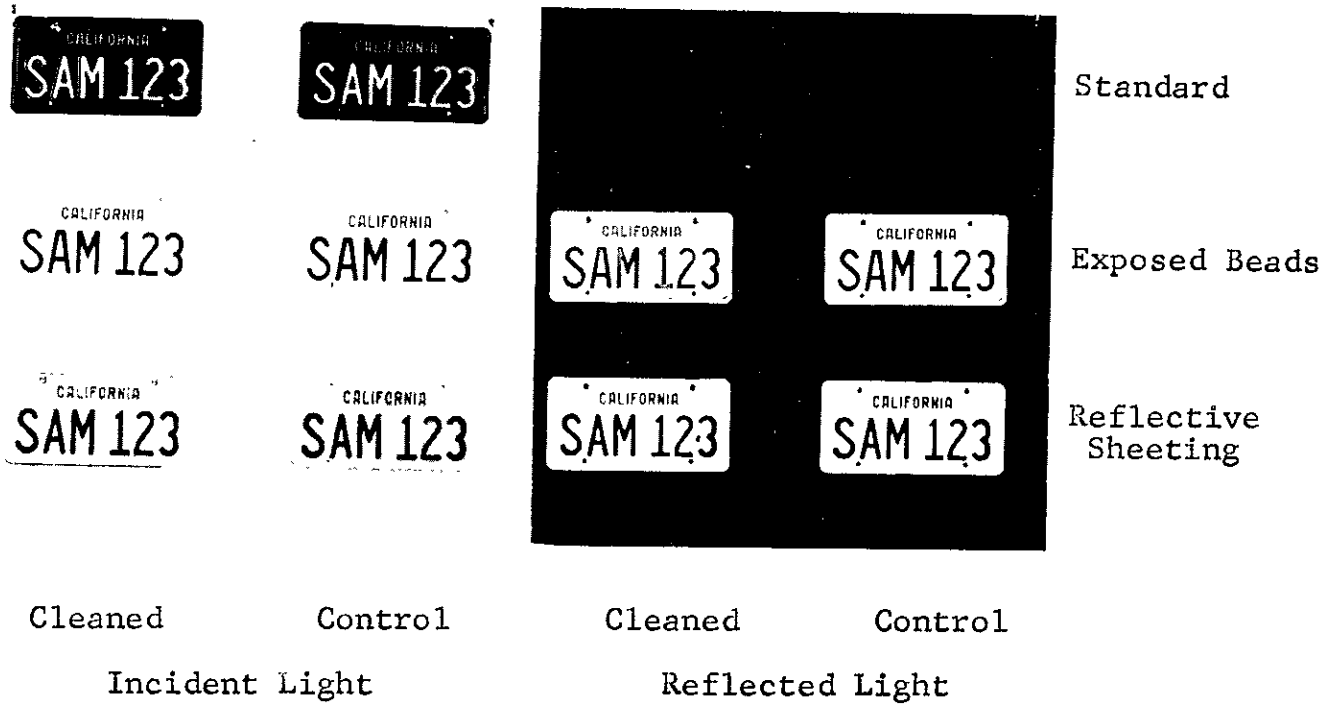

Figure 12

Soiled Specimens
After Cleaning With Soap And Water

Photometric evaluations showed that even though unremoved exhaust residue was evident on the exposed bead sample, reflectance was restored to 94% of its original after these repeated scrubbings. The reflectance of the reflective sheeting sample was restored to 93% of original by a light, single scrubbing (Figure 12). The average license plate will not be subjected to more than a light soap and water scrubbing.

After scrubbing with soap and water, the sample plates were then washed with gasoline followed by a water rinse as a further attempt at cleaning and to test their resistance to a frequently used solvent agent. The gasoline removed an additional amount of exhaust residue on the exposed bead sample, restoring its reflectance to 100% of original. There was no visible damage to the reflective system of either of the samples due to chemical action of the gasoline. However, the reflectance of the reflective sheeting sample was reduced to 90% of original, probably due to some dissolving of the finish clear-coat by the gasoline.

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The second set of soiled sample plates was mounted on the rear bumper of a standard automobile and washed in a commercial auto washing establishment where steam was employed to clean the bumper areas of the vehicle (Figure 13).

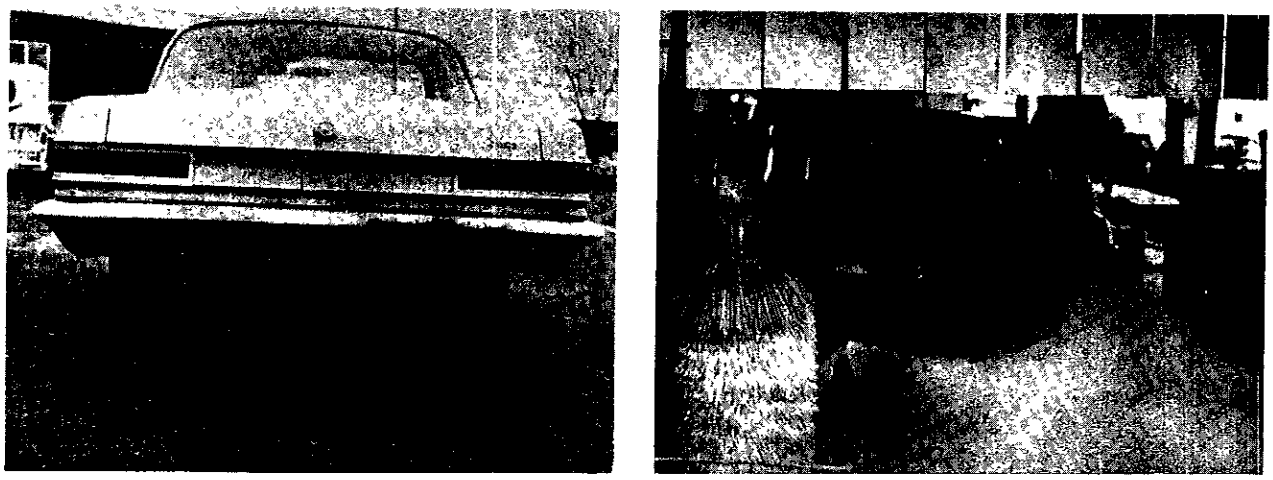

Figure 13

Soiled Specimens
Before and During the Washing Operations
in a Commercial Auto Washing Establishment

No damage to either reflective system was observed due to the steam cleaning. This type of cleaning operation was not as effective as the washing with soap and water, and by visual comparison neither the exposed bead, reflective sheeting or standard baked enamel plates were completely cleaned (Figure 14). However, this cleaning was probably representative of the cleaning the average license plate will receive. The reflectance of the exposed bead sample was restored to only 67% of original while the reflectance of the reflective sheeting sample was restored to 89% of its original reflectance.

Exhibit 12 tabulates the before and after reflectance values for all soiled and cleaned sample license plates.

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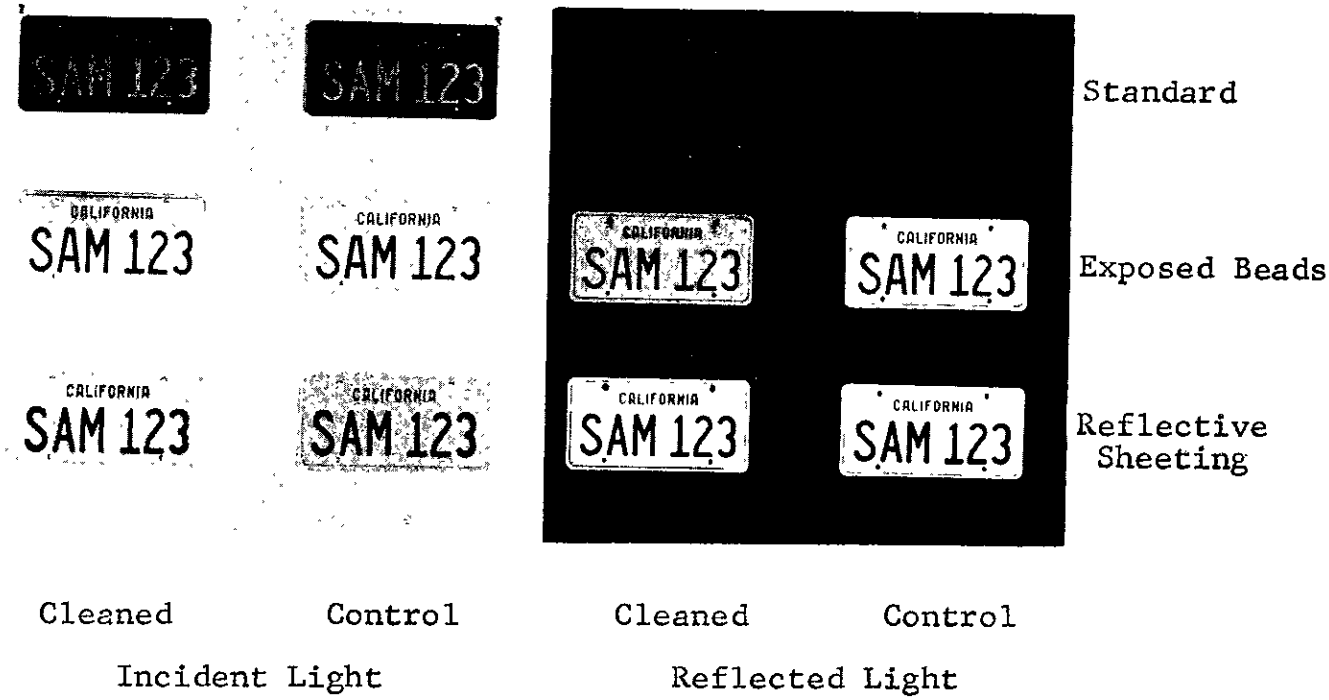

Figure 14

Soiled Specimens
After Steam Cleaning

The California Division of Highways has had similar experiences with the exposed bead reflective system in their highway signing and delineation field test program. For example, a number of exposed bead reflective highway marker plates were installed on Interstate Freeway 80 through Richmond in 1962. Photometric reflectance readings taken on one of these plates before cleaning, after two months of exposure to the freeway environment, showed an 80% loss in reflectance. Even after cleaning with soap and water, the reflectance reading on this marker plate was only 50% of the original reading. Reflective license plates would be mounted on vehicles exposed to this same environment.

Based upon the laboratory test results and field experiences with exposed bead reflective systems on highway signs and delineators, it is estimated that the average effective service life of this reflective material would be no greater than two years.

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7. Corrosion Resistance.

A comprehensive evaluation of the relative corrosion performance of different materials requires that the results of laboratory tests be compared to field performance. Due to the delay in receiving the samples of the various reflectorized license plates, sufficient time was not available in which to select an accelerated laboratory test which is known to give results that can duplicate the field performance of the materials. Nevertheless, in order to gain some rapid comparative results, the acetic acid-salt spray test was employed in the testing of the license plates. This test method is ASTM Designation: B287-62, "Acetic Acid-Salt Spray (Fog) Test".

At the conclusion of 322 hours of testing, the following types of license plates were considered to have resisted corrosion at least as well as the standard baked enamel California license plates:

a. Reflective sheeting with white background on aluminum base metal.

b. Exposed beads with white background on copper bearing steel.

The following license plates were considered to be more adversely affected by corrosion than the standard baked enamel California license plate:

c. Reflective sheeting with yellow background on galvanized steel.

d. Reflective sheeting with white background on copper bearing steel.

It should be noted that in no case was the legend area of any license plate scribed so as to simulate the effect of mechanical damage to the plate.

8. Reflectance Value (Test Method No. Calif. 642-A). (See Exhibit 13).

Reflectance measurements in candle power/foot candle/license plate (Specific Intensity) were made on samples of each type of plate to determine the material and color which would produce the highest degree of reflectance. These measurements were made with each plate in both a wet and dry condition. Initial measurements were made dry at 0° incidence angle to obtain the highest reflective value, followed by readings at angles of 10°, 20°, 30°, 40° right and left to measure angularity. Measurements were then repeated at 0° incidence angle

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with a fine spray of water directed onto the face of the plate to determine what effect, if any, simulated rain would have on the reflectance of each reflective system employed.

a. Reflective Sheeting.

In all instances the reflective sheeting samples produced the highest reflectance values. The reflectance at 0° ranged from a high of 18.4 for the sample with a reflective green legend and a reflective white background to a low of 2.3 for the sample with a reflective yellow legend and a nonreflective black background. Measurements obtained at from 0° to 20° incidence angles indicated only a slight loss in reflectance, with a greater loss recorded at the 20° to 40° incidence angles (approximately 50% loss at 40°).

The presence of moisture on the surface of these plates did not reduce the reflectance. In some cases, the presence of moisture increased the reflectance slightly. This increase was due to the specular gloss created by the beads of water.

b. Exposed Beads.

The reflectance of these plates at 0° incidence angle ranged from a high of 7.0 for a nonreflective black legend on a white reflective background to a low of 0.78 for a reflective yellow legend with a nonreflective black background. When measured at angles the exposed bead plates exhibited losses in reflectance proportional to those exhibited by the reflective sheeting. Measurements obtained at from 0° to 20° incidence angles indicated only a slight loss in reflectance, with a greater loss recorded at the 20° to 40° incidence angles (approximately 50% loss at 40°).

The presence of moisture on the surface of the exposed bead samples caused reductions in reflectance from 11% to 17% at a 0° incidence angle.

Exhibit 14 is a tabulation of the original reflectance values for all the license plates tested. See Figures 2, 3, 4, and 5 for photographic comparison under reflected light of the various types of license plates tested.

D. Visibility.

In all cases, license plates composed of the material and color combination exhibiting the greatest measured reflectance

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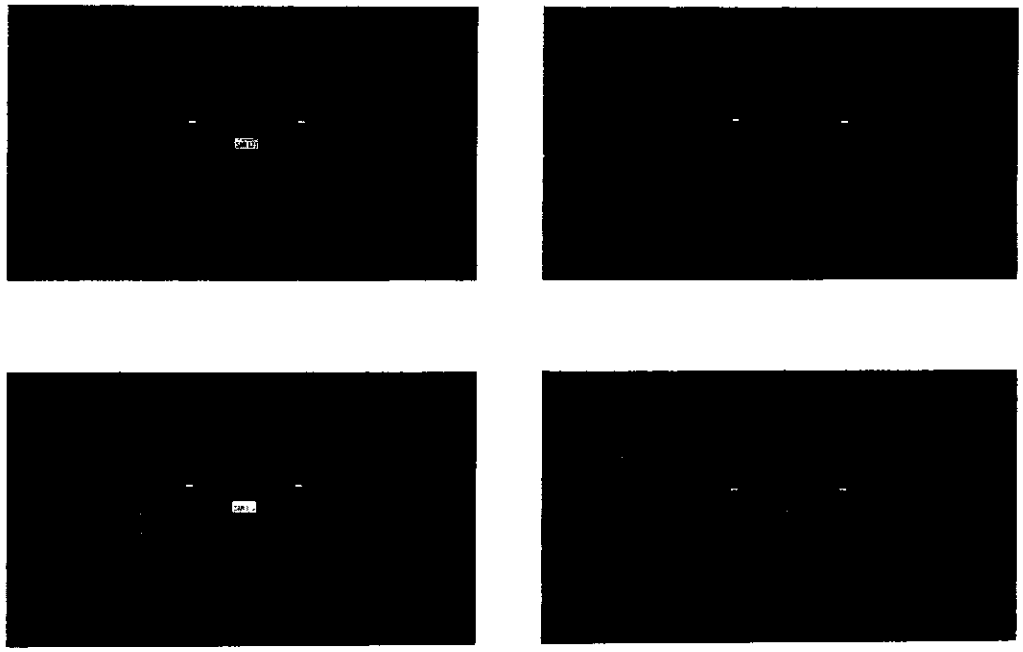
exhibited the greatest nighttime visibility or target value. Nighttime field evaluations revealed that license plates with fully reflectorized white backgrounds, of either of the reflective materials tested, are sufficiently reflective, when new, to be clearly visible at 600 feet. This is the accepted standard highway design stopping sight distance for a vehicle traveling at 70 mph. When the legend only is reflectorized, the reflective license plates are also visible at 600 feet. However, due to the small reflective area of the legend, any benefit derived as a warning target is questionable (Figure 15).



Exposed Beads

Reflective Sheeting

Background Reflective

Legend Reflective

Figure 15

Reflectorized License Plates Viewed At 100'

The nighttime field evaluations confirmed the laboratory findings that there was no significant loss of reflectance or visibility due to simulated rain with either the exposed bead or the reflective sheeting systems of reflectorization (Figure 16).

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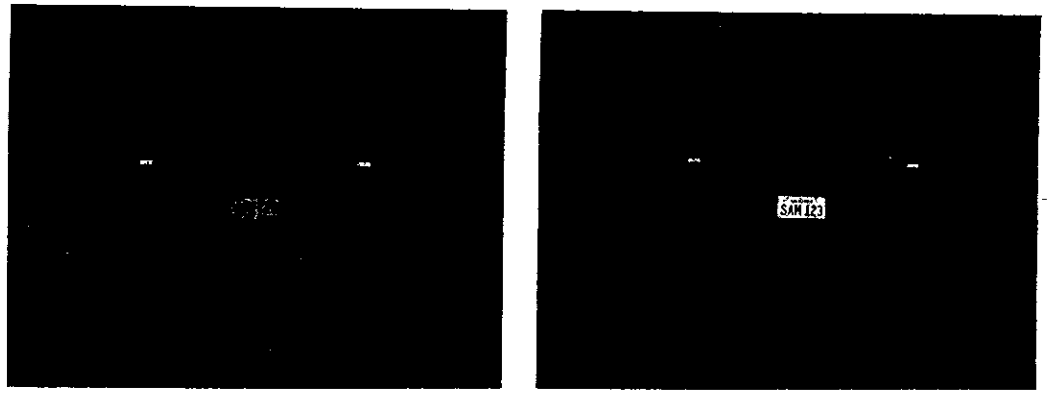

Exposed Beads Reflective Sheeting

Figure 16

Samples Viewed Under
Simulated Rain Conditions at 50 Feet

The nighttime field evaluations also confirmed the findings of other researchers[1,3,5,6] that the reflectorized license plates clearly indicated the position of a "one-eyed" approaching vehicle even when viewed under the most severe glare conditions produced by wet pavement (Figure 17).

Figure 17

Approaching "One-Eyed" Vehicle 75' Viewing Distance

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It must be pointed out that there are other equally effective means of providing nighttime warning targets for a parked or stalled vehicle. For example, as shown in the various photographs, the reflector portions of the tail lights on the test vehicle provided effective targets when viewed under reflected light (Figures 15 and 16). The California Vehicle Code: Section 24607, Article 3, Chapter 2, Division 12 (Exhibit 8) requires that vehicles be equipped with a red, rear reflector "of such size and characteristics and so maintained as to be readily visible at night from all distances within 300 feet to 50 feet from the vehicle when directly in front of lawful upper beams of headlamps". The standard highway design stopping sight distance for a vehicle speed of 45 mph is 300 feet. It appears that the 300 foot viewing distance requirement in the vehicle code is not great enough and should be at least doubled to meet the present day highway speeds.

In obtaining valid field evaluations, actual conditions were employed whenever possible. Photographs were taken of the sample plates at night, in dry and simulated wet weather, and at varying distances and headlamp modes.

E. Legibility.

Numerous studies have been made concerning the relative legibility characteristics of reflective vs nonreflective license plates with the findings showing in all cases that a reflective license plate is considerably more legible at night than a nonreflective plate. In a study performed by the University of Illinois[2], it was found that reflectorized license plates on the average increased the nighttime legibility (readability) distance over nonreflectorized plates by 28%.

Other significant findings, concerning the legibility of reflectorized license plates when viewed under reflected lights, contained in the Illinois[2] study are outlined below:

1. There appears to be no appreciable difference in legibility of the various types of materials used to reflectorize license plates.

2. Regardless of the type of material, character spacing, or the system of reflectorization, a wide stroke (7/16 inch) is required for maximum legibility distance when dark copy is used on a light background.

3. With a light legend on a dark background, a thin stroke (1/4 inch) is required for optimum legibility distance.

4. There is a correlation between the legibility distance of a reflectorized plate and the brightness contrast of

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the colors used. The legibility distance generally increases as the brightness contrast increases.

Applying the Illinois findings to the present California license plate legend design (1/4 inch stroke, etc.), the most nighttime legible (readable) reflective license plate would be obtained with a color combination comprised of a white reflective legend on a nonreflective background. The color combinations furnished for this California study are listed below in the order of their greatest legibility under reflected light:

1. Reflective white legend - nonreflective black, blue or green background.

2. Reflective yellow legend - nonreflective black background.

3. Reflective white legend - reflective blue background.

4. Reflective white legend - reflective green background.

5. Reflective green legend - reflective white background.

6. Reflective blue legend - reflective white background.

7. Nonreflective black legend - reflective yellow background.

8. Nonreflective black, blue or green legend - reflective white background.

Based on the results of the Illinois[2] study, the difference in legibility between the most legible and the least legible combination listed above is less than 13%. If the width of stroke and character spacing were varied in each of the above listed plates to give the best legibility, the difference in legibility between plates would be lessened. In fact, the listed order could be reversed. Figures 2, 3, 4, and 5 show the comparative nighttime legibility of the sample plates.

For daytime legibility, reflectorization is of no consequence and the order of legibility is primarily dependent on the contrast ratio between the legend and background colors. The color combinations tested all have excellent contrast ratios and good legibility characteristics. No attempt was made in this study to determine which combination is the most legible for daylight observations. Figures 2, 3, 4, and 5 present all the tested color combinations under normal daytime illumination.

All materials tested had good reflective angularity and were clearly legible under reflected light at angles up to 60° (Figure 18).

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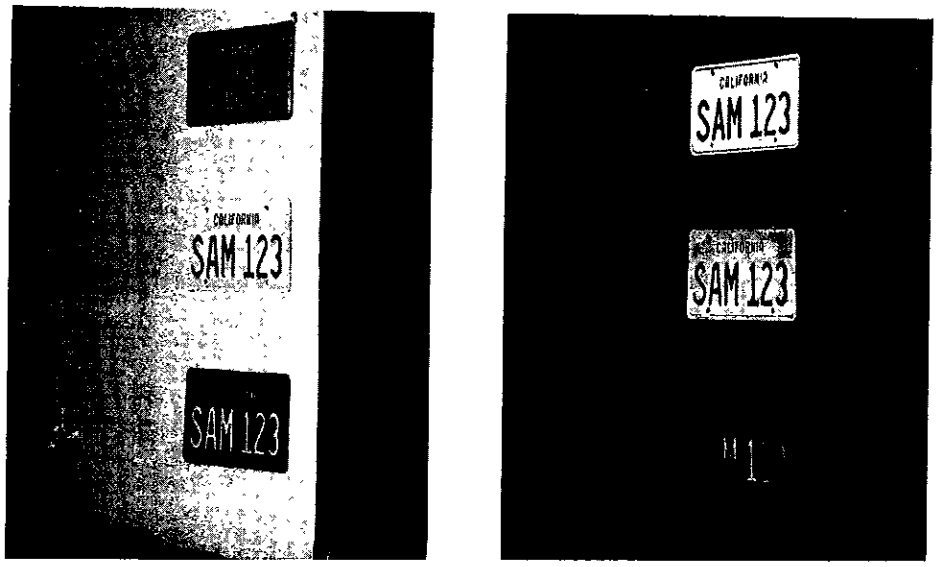

Reflective Sheeting

Exposed Beads

Exposed Beads

Incident Light

Reflected Light

Figure 18

Specimens Viewed From 15 Feet at 60 Degrees

Nighttime field evaluations confirmed the California Highway Patrol findings[1] on the legibility of the license plates of approaching vehicles (Figure 19), namely: that reflectorized license plates are legible when viewed against the high beam headlights of an oncoming vehicle.

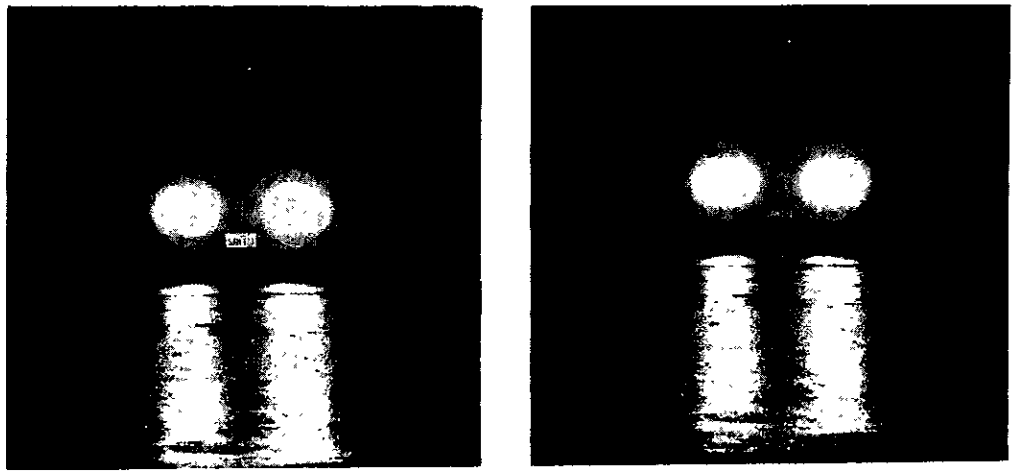

Figure 19

Comparative Legibility of Reflective Sheeting System
Against Oncoming Headlights.
Viewed at 75 Feet on Wet Pavement.

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F. Economics

Production, material, and equipment costs for adding reflectorization to California's license plates could amount to a considerable sum depending on the extent of reflectorization and the type of reflective system adopted. A survey of current vehicle registration figures reveals that approximately four million single replacement plates are issued annually and that in excess of thirty million single plates would be required if the next general issue is in 1970. This amounts to a four year production run at the present manufacturing capacity of the Correctional Industries license plate shop at Folsom Prison.

The total cost of the current baked enamel, copper bearing steel license plate in quantities over two million to the Department of Motor Vehicles is $0.11 per unit, or $0.22 per pair. The life expactancy of this plate is not established; however, all indications are that a 10 to 15 year life span is not unreasonable. Using these figures the average cost per pair of plates per year is less than $0.02. Therefore, this current plate provides the most economical licensing and registration unit possible. However, the baked enamel finish exhibits low nighttime legibility and no target value as a safety device.

To obtain these added features requires the additional expense of reflectorization. A single specific dollar amount for reflectorization cannot be quoted due to the various material combinations available. However, figures for each type reflective system are listed and a detailed cost breakdwon for one of the systems is tabulated (see Exhibit 15).

1. Reflective Sheeting.

This is the most expensive of the reflective systems available, both in materials cost and the additional application equipment requirements (see Exhibit 15). In addition, it is not recommended that this material be applied to the copper bearing steel currently being used in California. The reflective sheeting manufacturer recommends its application to either galvanized steel or aluminum.

The total cost per pair for reflective sheeting license plates would be:

Galvanized steel substrate	$0.78
Aluminum substrate	$0.84

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Based on an estimated four year average effective life span, the total approximate cost per pair per year would be:

Steel substrate	$0.195
Aluminum substrate	$0.21

The cost difference between different colors and between reflectorized background only and reflectorized legend only is negligible. Both methods require the entire license plate be covered with sheeting and either the legend or background roller coated.

2. Exposed Beads.

Although this reflectorized system is the most economical available, its average effective life span is undetermined. However, figures are presented based on a two year replacement cycle because of anticipated critical loss of nighttime visibility and legibility due to loss of reflectiveness and discoloration from soiling and staining.

This material can be effectively applied to any substrate, including the copper bearing steel in current use.

Due to the physical make-up of this reflective system, there is a considerable price difference between reflectorization of background and legend. The lens elements (beads) are embedded in the enamel on only that portion of the plate which is to be reflectorized. As the legend area is much less than the area of the entire plate, bead material costs for legend only would be less than for reflectorizing the background.

The total cost per pair for exposed bead license plates would be:

Steel substrate,	reflective background	$0.36
	reflective legend	$0.27
Aluminum substrate,	reflective background	$0.40
	reflective legend	$0.31

Based on a subjective two year life span, the approximate total cost per pair per year would be:

Steel substrate,	reflective background	$0.18
	reflective legend	$0.135
Aluminum substrate,	reflective background	$0.20
	reflective legend	$0.155

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These figures are based on current material costs. The reflective bead industry indicates that through competition the price of beads could be reduced as much as 60%.

The cost for the additional equipment required by the Department of Corrections for this system is estimated at $7,500.

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VI. BIBLIOGRAPHY

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2. The Function and Design of Motor Vehicle License Plates, Baerwald, J. E., D. F. Karmeier, and C. G. Herrington, University of Illinois (1960).

3. A Study of the Effectiveness of Reflectorization of License Plates and Its Significance to the Highway Safety Program of the State of Washington, E. G. Brown, University of Washington (1964).

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5. The Road User and the Improvement of Vehicle Registration Plates, Michel Grey (1963).

6. The Reflective Registration Plate, Kare Rumar, University of Uppsala, Sweden (1966).

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STATE OF CALIFORNIA—HIGHWAY TRANSPORTATION AGENCY

EDMUND G. BROWN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

August 10, 1966
File: License Plate Study
Project W.O. 646395

Dear Sir:

In the first extraordinary session of the 1966 session of the California Legislature a resolution was passed in the Assembly requesting that the California Division of Highways "conduct tests on the use of reflective license plates and to report its findings and recommendations to the Assembly on or before the fifth legislative day of the 1967 regular session of the Legislature".

Through preliminary discussion it was determined that the requested study would include comparative tests of those materials applicable to license plates. Testing and evaluation will be performed by the Materials and Research Department and will include the following:

1. Abrasion endurance.
2. Fade resistance.
3. Adherence to base material.
4. Legibility under daylight and reflected light under all weather conditions.
5. Reflectance, under all weather conditions.
6. Resistance to soiling.
7. Ease of cleaning
8. Resistance and endurance to sandblast, steam and solvents.

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Reflective system manufacturers who desire to participate in this study will be requested to furnish samples of their material on 6" x 12" embossed steel license plate blanks.

For the series of tests proposed we will require from each participating manufacturer the following samples:

1. 20 each Reflectorized silver or white background with black legend.
2. 2 each Reflectorized silver or white background with blue legend.
3. 2 each Reflectorized silver or white background with green legend.
4. 2 each Reflectorized yellow background with black legend.
5. 2 each Blue background with reflectorized silver or white legend.
6. 2 each Green background with reflectorized silver or white legend.
7. 2 each Black background with reflectorized silver or white legend.
8. 2 each Black background with reflectorized yellow legend.

If you are interested in submitting samples for evaluation would you please answer the following questions in your reply:

1. What base material is your product best applied to? Is steel (alloy copper bearing, 8 pt. carbon, cold rolled .0209th.) satisfactory?
2. Would you be able to furnish the color combinations listed? If not, which ones?
3. If we furnished the steel blanks, could you apply all reflectorization and legend?
4. Charges, if applicable, should be billed in triplicate to the Materials and Research Department, 5900 Folsom Boulevard, Sacramento, California 95819.

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We would appreciate an answer from you or your representative at your earliest convenience. We will assume that no acknowledgment indicates that you are not interested in participating in this study.

If additional information is needed please feel free to call on us.

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

By

Eric F. Nordlin
Assistant Materials and Research Engineer - Structural

EFN:RNF:RAP:bk

cc:

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The same letter to:

Flex-O-Lite Manufacturing Corporation
8301 Flex-O-Lite Drive
P. O. Box 3066 (Afton Branch)
St. Louis 23, Missouri

cc: Mr. F. G. Collins
Flex-O-Lite Manufacturing Co.
3209 Adeline Street
Berkeley, California 94703

Cataphote Corporation
Jackson, Mississippi

cc: Mr. Martin Anson O'Brien
510 46th Street
Sacramento, California

Prismo Safety Corporation
Huntingdon, Pennsylvania

cc: Mr. Harold L. Clements
1255 S. Lewis Street
Anaheim, California

Minnesota Mining and Manufacturing Company
Reflective Products Division
367 Grove Street
St. Paul 1, Minnesota

cc: Mr. Mel A. Krohn
4516 Santa Lucia Drive
Woodland Hills, California

Hawkins-Hawkins Co., Inc.
1255 Eastshore
Berkeley, California 94710

cc: Mr. Norman L. Hawkins, Jr.
Address - Same

Avery Products Corp
Development Division
125 West Green Street
Pasadena, California

cc: Mr. Austin H. Herbst
Address - Same

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EXHIBIT 2

AVERY PRODUCTS CORPORATION
CORPORATE RESEARCH CENTER
125 WEST GREEN STREET • PASADENA, CALIFORNIA 91101

October 13, 1966

Mr. Chuck Ledbetter
California Division of Highways
Materials & Research Department
5900 Folsom Boulevard
Sacramento, California 95819

Subject: License Plate
Study - W.O.646395

Dear Mr. Ledbetter:

I tried to call you this morning but your lines were busy. We will be unable at this time to send you sample specimens of our retro-reflective sheet material which has been applied to your license plate blanks.

The reason for this delay is that we have been unable to schedule a pre-production run of our proprietary high index glass bead formulation. This work is scheduled for December.

We are very much interested in qualifying our product with your division and will contact you as soon as materials are available. If you do not need the license plate blanks we will keep them.

Very truly yours,

Austin H. Herbst

Austin H. Herbst, Manager
Process and Product Development

AHH:jb

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EXHIBIT 3

PHONE· JACKSON, MISS. 601-939-4612
TWX. 601-948-2314

CATAPHOTE CORPORATION

MANUFACTURERS OF REFLECTIVE TRAFFIC PRODUCTS

TOLEDO 10, OHIO, U. S. A. OR JACKSON, MISSISSIPPI, U. S. A.

PLEASE ADDRESS REPLY TO:
P. O. BOX 2369
JACKSON, MISSISSIPPI—39205

October 14, 1966

State of California
Department of Public Works
Division of Highways
5900 Folsom Boulevard
Sacramento, California 95819

Attention: Mr. John L. Beaton
Materials & Research Engineer

Dear Mr. Beaton:

In reference to your letter of October 7, Cataphote Corporation would prefer to decline submitting samples for License Plate Study, Project W.O.646395.

Very truly yours,

CATAPHOTE CORPORATION

H. W. Smalley
Vice President - Sales

HWS/nr

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EXHIBIT 4

EFLECTIVE GLASS BEADS FOR TRAFFIC ZONE MARKING AND SIGNS
"BLASTOLITE" THE QUALITY BEAD FOR CLEANING AND PEENING

MANUFACTURING CORPORATION
TELEPHONE ... FLANDERS 1-4450
P.O. BOX 4366 (AFFTON BR.)
ST. LOUIS, MISSOURI • 63123

August 19, 1966

State of California
Highway Transportation Agency
Department of Public Works
Division of Highways
Materials and Research Department
5900 Folsom Blvd.
Sacramento, California 95819

Attention: Mr. John L. Beaton,
Materials and Research Engineer

Refer To: Mr. Eric F. Nordlin
Asst. Materials and Research Engineer-Structural

SUBJECT: YOUR LETTER AUGUST 10th, 1966 FILE LICENSE PLATE STUDY PROJECT WO646395

Dear Mr. Nordlin:

In line with subject letter, we wish to advise that we would like to participate in the California License Plate study.

In order to enter samples for our materials in the tests proposed, we will need 44 embossed license plate blanks and would appreciate sending these to us.

The answers to the questions enclosed in your letter are as follows:

1. Our materials may be applied to any of the license plate materials. Steel (alloy copper bearing, 8 PT. carbon, cold rolled .0209th) is satisfactory.

2. Yes, we would be able to furnish the color combinations listed.

(Continued on page 2)

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3. Yes, if you would furnish the steel blanks, we could apply all reflectorization and legend.

4. There will be no charges.

We hope the above information is satisfactory and we will be looking forward to hearing further from you.

Very truly yours,

R. D. Freihofer
Director of Sales

RDF:dpm

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EXHIBIT 5

Hawkins*

THE NAME IN HIGHWAY SAFETY

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September 30, 1966

State of California
Highway Transportation Agency
Department of Public Works
Division of Highways
Materials and Research Department
5900 Folsom Blvd.
Sacramento, California 95819

Attention: Eric F. Nordlin
Assistant Materials and Research Engineer - Structural

Subject: File: License Plate Study,
Project W.O. 646395

Dear Mr. Nordlin:

We refer to your letter of August 10, 1966, relative reflective material for license plates study.

Unfortunately, at this time we are in the process of changing formula insofar as chemistry and mechanical technique in the production of a wide angle smooth finish reflective sheeting suitable for embossed plates. You can appreciate any sample submitted at this time would be essentially different from an ultimate product. We must of necessity waive the opportunity to submit sampling material during your current test program.

In the near future we may be able to provide a sheeting for the end usage. Basically, 3M patents have created an obstacle causing extreme difficulty in producing a comparable sheeting to "Scotchlite". We recommend serious consideration to the use of glass beads on baked enamel surface since the economy and opportunity for competitive bidding is well established.

If our situation changes, we will contact your office promptly. In the meanwhile, please accept our appreciation for the invitation to participate in this evaluation program.

Very truly yours,

HAWKINS-HAWKINS CO., INC.

Norman L. Hawkins, Jr.
Norman L. Hawkins, Jr.
General Manager, Sales & Products

NLH:gt

10/3/66

* REGISTERED U.S. PAT. OFFICE
Designers, Manufacturers, Engineers and Distributors of
VISUAL, PHYSICAL AND MECHANICAL AIDS AND DEVICES FOR HIGHWAY AND STREET TRAFFIC SAFETY

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3M COMPANY

GENERAL OFFICES • 2501 HUDSON ROAD • ST. PAUL, MINNESOTA 55119 • TEL. 733-1110

Reflective Products Division

August 19, 1966

Department of Public Works
Division of Highways
Materials and Research Department
5900 Folsom Boulevard
Sacramento, California 95819

Attn: Mr. Eric F. Nordlin,
Assistant Materials and Research
Engineer -- Structural

Gentlemen:

As indicated in our letter of August 15th, we would like to participate in your test of reflective license plates under Project W.O. 646395 as outlined in your letter of August 10th.

In answer to the four questions in your letter, we submit the following:

1. The best base materials for application of our reflective sheeting for license plate use are either aluminum with a conversion coating such as Alodine 1200, or continuous mill galvanized steel with a continuous mill phosphate surface treatment.

   Alloy copper bearing 8 pt. carbon, cold rolled steel, .0209th would be satisfactory for a one-year issue only. After one year it tends to corrode on edges and backside and also at scratched areas. Aluminum and galvanized steel do not show rust corrosion with multi-year exposure.

2. We can furnish all of the color combinations listed. The dark background plates (blue, green and black) would need to be debossed rather than embossed. The States of Vermont and West Virginia are presently making debossed plates with our materials.

   Debossed blue and green background plates can be completely reflectorized, using transparent roller coating paint. With the black background, only the copy would be reflectorized.

continued.....

EM 8/22 file 8/31

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3. We can apply all reflectorization to your flat blanks if we can use our own dies. We do not have California size or style dies, but do have both embossing and debossing dies designed for license plates, including rim dies.

   However, we would prefer to use aluminum or galvanized steel blanks of the types described in #1 above for multi-year use. For one-year service life plates, California copper bearing cold rolled steel blanks would be satisfactory. We can supply the aluminum or galvanized blanks.

4. We will supply all materials and finished samples at no charge.

If our recommendations meet with your approval, please let us know and we will prepare and submit the samples according to your list.

We will welcome any questions you may have. If time becomes a factor, you may wish to phone collect to the undersigned at area code #612 phone 733-0591.

The opportunity to participate in your proposed study is sincerely appreciated.

Yours very truly,

R. M. Husbands,
Reflective Products Division

RMH/smj

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GENERAL OFFICES • 2501 HUDSON ROAD • ST. PAUL, MINNESOTA 55119 • TEL. 733-1110

Reflective Products Division

September 29, 1966

Materials & Research Dept.
California Division of Highways
5900 Folsom Blvd.
Sacramento, California

Attn: Mr. Robert Field

Gentlemen:

In our discussion of your proposed tests of reflectorized license plates, we have considered only plates made with our "REFLECTO-LITE" Brand Reflective Sheeting. We have not proposed the use of our "CODIT" Brand Reflective Liquid for these tests.

There are several reasons why we have not suggested and do not recommend this product be included in your study.

1. "CODIT" Reflective Liquid is an exposed lens system, and has two inherent characteristics of exposed lens reflective materials which make it less desirable for license plates than a smooth surface reflective sheeting.

    a. The tendency to accumulate dirt which cannot be easily removed, with a resulting progressive loss in reflective brightness, and

    b. Substantial loss of reflection in rainfall results in reflection little better than a painted plate.

2. The availability of colors is limited and would preclude many desirable color combinations.

3. More complicated production methods are required for application of "CODIT" Liquid than for reflective sheeting.

It is for these reasons that we propose to supply test plates made with reflective sheeting only.

Sincerely,

R. M. Husbands,
Reflective Product Sales

RMH:mfk

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HUNTINGDON, PENNSYLVANIA

November 23, 1966

State of California
Division of Highways
Materials & Research Dept.
5900 Folsom Blvd.
Sacramento, California 95819

Attention: John L. Beaton, Materials & Research Engineer

File: License Plate Study, Project W.O. 646395

Gentlemen:

We appreciate the invitation to participate in the reflectorized license plate study being conducted by your department. We do, however, feel we must decline your invitation at this time. Some of the factors effecting our decision are as follows:

1. Comprehensive testing procedures have not been outlined or described.

2. The desired end result whether it be target value, angularity, longevity, or the anticipated benefits to the California motorist versus cost are not clarified.

3. If adopted, would the replacement program be an annual one, or on a 5 year or a 10 year basis?

4. Questionable value of the program in terms of accident prevention.

Prismo Safety Corporation as one of the pioneers in the field of reflective license plates, frankly questions the actual safety benefits of reflective license plates when related to accident prevention. Our initial work in this field was done when automobiles had smaller tail lights and considerably less reflective material in and around the tail light area.

continued

Beaton 11/28
EJM 11/28

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PRISMO SAFETY CORPORATION
HUNTINGDON, - - - PENNSYLVANIA

Assuming that additional reflectorization on the rear of an automobile is the desired end result, then perhaps Section 24607, Article 3, Chapter 2, Division 12 of the Vehicle Code should be re-evaluated. This would then require auto manufacturers to incorporate more reflective material in their design and thus relieve the taxpayers in California of an additional expense which has questionable value in terms of traffic safety.

The legislative analysts report of 1965 regarding the cost of reflective license plates, places the first year cost in excess of $1,000,000.00. Within seven years the cost could be in excess of $8,000,000.00. The above costs could be reduced by approximately 70% depending on the type of reflectorizing materials used.

Expenditures of this magnitude might well be used for other highway safety programs whose value in terms of safety and lives saved have been established and proven.

Very truly yours,

PRISMO SAFETY CORPORATION

D. A. Reese, Jr.
Vice President
Sales & Marketing

/js

cc: Eric F. Nordlin
Asst. Materials & Research Engineer - Structural

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Reflectors on Rear

24607. (a) Any vehicle of a type subject to registration under this code not otherwise required under the provisions of this code to be equipped with rear red reflectors shall carry on the rear, either as a part of the tail lamps or separately, one red reflector meeting the requirements of this section and of a type approved by the department.

(b) The reflector shall be mounted on the vehicle at a height not less than 16 inches nor more than 60 inches and shall be of such size and characteristics and so maintained as to be readily visible at night from all distances within 300 feet to 50 feet from the vehicle when directly in front of lawful upper beams of headlamps.

(c) Any reflector installed upon a vehicle as a part of its original equipment prior to January 1, 1941, need not be of a type approved by the department if it meets the requirements of subdivision (b) of this section.

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State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Test Method No. Calif. 645-A
July, 1963
(2 pages)

METHOD OF TEST FOR PAINT ADHERENCE OF BAKED ENAMEL SIGNS AND GUIDE PLATES

Scope

This test method describes a procedure used to determine whether effective paint adherence has been provided in the process by which metal sheets (used for signs and guide plates) were prepared for painting.

Procedure

A. Apparatus

1. A sharp instrument for scratching the paint film.
2. A water bath in which the specimen can be submerged and the temperature maintained at 95 F. ± 3 F.
3. Masking tape conforming to Code No. 250, Minnesota Mining & Manufacturing Company (age of tape not to exceed 6 months).
4. Bend test apparatus (See Fig. 1).

B. Preparation of Test Specimens

1. The test specimen consists of a 4″ x 8″ sheet of the metal used in the production of the signs or guide plates which has been prepared for painting and has been painted in the same manner and at the same time as the lot of signs or guide plates represented by the specimen.
2. Using a sharp instrument, make two diagonal scratches connecting opposite corners on both sides of the specimen. Make the scratches deep enough to penetrate through the paint film and coating, exposing the base metal.

C. Test Procedure

1. Submerge the specimen in distilled or demineralized water maintained at a temperature of 95 F. ± 3 F. for 192 hours (8 days).
2. At the end of the 192 hours soaking period remove the specimen from the water and inspect visually for evidence of blistering, softening, or peeling of the paint from the base metal on either side of the specimen.
3. Within 5 minutes after removing the specimen from the water, wipe the surface dry with a soft cloth and apply a one-inch wide strip of the masking tape with the adhesive side down across the intersection of the diagonal scratches. Apply a strip of tape to each side of the specimen. Press the tape tightly against the surface of the coating by passing a rubber roller across the tape at least twice. Remove the tape with one quick motion and inspect the specimen for peeling of the paint from the base metal.
4. Subject the specimen to a 180° bend around a ½″ round mandrel, using the apparatus shown in Fig. 1, and inspect for flaking or chipping of the paint from the metal.

Reporting of Results

Report results on Form T-616. Specimens which show any evidence of flaking, chipping, blistering, softening, or peeling of the paint from the metal at any stage of the test shall be reported as having failed the test.

REFERENCE

A California Method

End of Text on Calif. 645-A

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ABRASION TESTS (TABOR ABRADER)

Material	Min. Revolutions to Failure
CS-10 Abrasive Wheel at 1000 Gram Load	
Exposed Beads - White	No effect after 1300
Reflective Sheeting - White	1000
Reflective Sheeting - Yellow	1000
Reflective Sheeting - White Roller Coated Black	200
Reflective Sheeting - White Roller Coated Green	200
Reflective Sheeting - White Roller Coated Blue	200
Standard Baked Enamel - Black	400
Standard Baked Enamel - Black Roller Coated Yellow	200
H-22 Abrasive Wheel at 500 Gram Load	
Exposed Beads - White	100
Reflective Sheeting - White	100
Reflective Sheeting - Yellow	100
Standard Baked Enamel - Black	35

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REFLECTANCE VALUES FOR SANDBLASTED LICENSE PLATES

(BLACK NONREFLECTIVE LEGEND - WHITE REFLECTIVE BACKGROUND)

Material	Candle Power/Foot Candle/Plate (Specific Intensity)				
	0°	10°	20°	30°	40°
Reflective Sheeting					
Original:	17.6	17.6	15.6	12.9	9.8
Light Sandblast:	9.0	8.2	7.4	5.8	4.3
Heavy Sandblast:	No measurable reflectance.				
Exposed Beads					
Original:	7.0	6.6	5.5	4.3	4.9
Light Sandblast:	1.9	1.9	1.6	1.6	1.2
Heavy Sandblast:	No measurable reflectance.				

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REFLECTANCE VALUES FOR SOILED LICENSE PLATES

(BLACK NONREFLECTIVE LEGEND - WHITE REFLECTIVE BACKGROUND)

Material	Candle Power/Foot Candle/Plate (Specific Intensity)				
	0°	10°	20°	30°	40°
Reflective Sheeting					
Original:	17.6	17.6	15.6	12.9	9.8
Soiled:	1.56	1.56	1.17	1.17	0.78
Cleaned w/soap & water:	16.2	15.6	14.5	12.0	9.1
Cleaned w/gasoline:	15.8	15.3	13.8	11.1	8.5
Steam cleaned:	15.6	14.8	13.3	10.9	7.8
Exposed Beads					
Original:	7.0	6.6	5.5	4.3	3.9
Soiled:	0.78	0.39	0.39	0.39	0.39
Cleaned w/soap & water:	6.6	6.3	5.1	3.9	3.1
Cleaned w/gasoline:	7.0	6.6	6.2	5.1	3.9
Steam cleaned:	4.7	4.7	3.9	3.1	2.3

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State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Test Method No. Calif. 642-A
July, 1963
(2 pages)

METHOD OF TEST FOR REFLECTANCE OF REFLECTIVE SHEETING FOR HIGHWAY SIGNS

Scope

This method covers the procedure for measuring the reflectance of reflective sheeting in units of "candlepower per foot candle per square foot" under standardized test conditions.

Procedure

A. Apparatus

1. Leeds and Northrup 9835-B stabilized D.C. indicating amplifier.
2. D.C. microammeter, G.E. DP-9.
3. Reflective sheeting mounting plate and Goniometer with a horizontal scale of 0° to 70° right and left.
4. Four photocells, Weston Model 594 RR-OV, and mounting plate that will slide snugly into the mounting bracket on the Goniometer.
5. 117 V. – 6.3 V. transformer, 10 amp., 60 cycle.
6. Black opaque cloth, one square yard.
7. Sealed beam spotlamp, G.E. 4515, and a portable assembly for mounting the spotlamp, transformer, and photocell assembly.
8. Sorensen voltage regulator, 115 V.A.C., Model No. 500-S.
9. 20,000 ohm resistor.
10. Leeds and Northrup resistance decade box, 0 to 1000 ohm range.
11. 100 ohm Helipot potentiometer.
12. 1.34 volt mercury cell, or equivalent cell of stable voltage.
13. Two 33″ high steel stands made of 6″ pipe with ⅜″ end plates, 12″ square.

B. Control Factors

1. A corridor or "light tunnel" of 60 feet minimum length shall be employed for this test and the entire area of the light tunnel and all objects or equipment in the area shall be painted a flat, nonreflective black.
2. The test distance between the reflective sheeting stand and the combination sealed beam spotlamp and photocell stand shall be 50 feet.
3. New sealed beam spotlamps shall be seasoned under normal operating voltage for 20 hours prior to employment in the performance of reflectance tests.
4. The equipment is arranged and connected as shown in Figure I.
5. The four photocells shall be centrally placed on the mounting plate with their centers spaced at 90° intervals on the circumference of a 7 inch diameter circle. This arrangement provides a divergence angle of ⅓° at a test distance of 50 feet. A 4⅞ inch diameter opening concentric with the above 7 inch diameter circle shall be provided in this mounting plate to permit the entrance of the light beam from the spotlamp.
6. The 0° reading on the Goniometer shall designate the 0° incident light position as measured on a horizontal plane.
7. The centers of the spotlamp, the photocell array and the reflective sheeting panel shall be placed in a straight line and on the same horizontal plane. The photocell assembly shall be positioned perpendicular to the axis of the light beam in both the horizontal and vertical planes. The reflective sheeting shall be placed perpendicular to the light beam in the vertical plane and at 0° incident light shall be 90° to the light beam in the horizontal plane.
8. To avoid saturation of the amplifier, the output current should be limited to a maximum of 100 microamperes by the selection of a suitable shunt resistor to the input of the amplifier.
9. A 3″ reflector button, mounted on a plate that will slide snugly into the mounting bracket on the Goniometer and position the reflector button in accordance with the positioning described in B-7, is employed as a stability check on the operation of the equipment.
10. The spotlamp, after being centrally focused on the reflective sheeting in the test position, shall not be moved throughout the test.

C. Preparation of Samples

1. The test is performed on reflective sheeting applied to the intended sign-backing material. To obtain comparable test results, the sheeting must be free from letters, edgings, insignia, holes, and scratches. Remove foreign substances such as smudges or dust from the reflective sheeting.

D. Test Procedure

1. Arrange the apparatus as shown in Figure I.
2. Turn on the power to the equipment and confirm that the spotlamp is connected into the regulated power supply and at the proper voltage. Place the photocell assembly into the Goniometer mounting bracket normally occupied by the reflective sheeting assembly. Focus the spotlamp onto the center of the photocells. Allow the test equipment a 15 minute warm up period; if, after this initial warm up time the incident light reading is constant over a 5 minute test interval, the equipment is assumed to be stabilized and ready to use for the testing.
3. Obtain the incident light value from the spotlamp by the following method:

   a. The photocell assembly remains in the Goniometer's mounting bracket.

   b. To avoid damaging the microammeter, set the microammeter on the 1000 microampere scale until a suitable lower scale is determined. Set the scale multiplier selector on the Leeds and Northrup amplifier on 40. Select the 20 ohm resistor in the decade box. Expose the photocells to the 0° incident light rays, close the switch and select a suitable meter scale.

   c. Cover the photocells with a black opaque cloth to exclude all light; zero the meter with the bucking current potentiometer.

   d. Remove the black opaque cloth and record the microammeter reading.

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e. Move the photocell assembly to the normal position adjacent to the spotlamp.

4. Slide the stability checking reflector button with mounting plate into the Goniometer's mounting bracket set in the 0° position. In general, set the resistance between 20 to 100 ohms on the decade box; set the scale multiplier switch on 1. Close the switch to the microammeter and select a suitable meter scale; cover the reflector button with a black opaque cloth; zero the microammeter with the bucking current potentiometer; remove the black opaque cloth and record the microammeter reading.

5. Remove the check button assembly from the Goniometer's mounting bracket and insert the reflective sheeting assembly. In general, set the resistance on the decade box between 20 and 100 ohms, the scale multiplier switch is retained at 1. Place the reflective sheeting on the mounting plate. Close the switch to the microammeter and select a suitable scale. Cover the reflective sheeting with a black opaque cloth and zero the meter with the bucking current potentiometer. Remove the black opaque cloth. The reflective sheeting is rotated about the vertical axis and the reflected light readings shall be recorded for 0° and 10°, 20°, 30°, 40° and 45° right and left.

6. Repeat test procedure D-4 after measuring each reflective sheeting to ensure that the incident light reading remains unchanged.

E. Calculations

From the readings obtained calculate the reflectance in candlepower per foot candle per square foot of reflective area as follows:

$R.L.$ = Microammeter reading of reflective sheeting × scale multiplier.

$I.L.$ = Microammeter reading of photocells × scale multiplier × $\frac{S.R.}{S.I.}$

Where

$R.L.$ = Reflected light of reflective sheeting under test, determined as described in D-5 above.

$I.L.$ = Incident light determined as described in D-3 above.

$S.R.$ = Value in ohms of the shunt resistance in the decade box employed for the reflective sheeting microammeter reading.

$S.I.$ = Value in ohms of the shunt resistance in the decade box employed for the incident light microammeter reading.

Scale Multiplier: Reading on amplifier output select switch.

Then

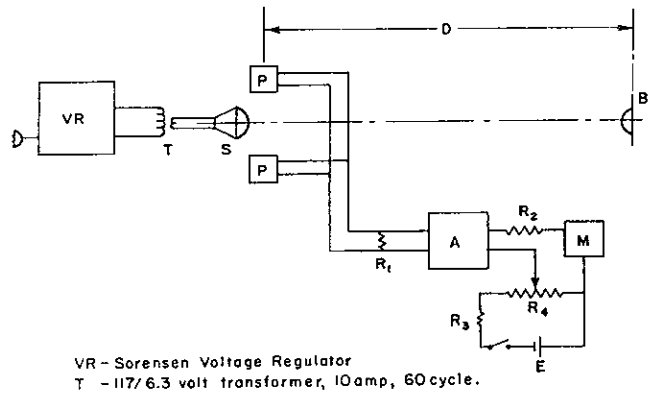
The candlepower per foot candle per square foot

$$= \frac{R.L. \times D^2}{I.L. \times A}$$

Where

D = Distance in feet from photocells and spotlight to reflective sheeting. (50 feet)

A = Area in square feet of the panel of reflective sheeting used. (Usually 8″ x 8″ panel)



VR - Sorensen Voltage Regulator
T - 117/6.3 volt transformer, 10 amp, 60 cycle.
S - GE Spotlamp # 4515
P - Two Weston Photo cells # 594-RR-OV. (Total of four employed in test)
B - Reflective Material.
D - Test Distance
A - Leeds and Northrup 9835-B Stabilized DC indicating amplifier.
M - DC Microammeter, G.E. DP-9.
E - 1.34 Volt mercury cell.
R_1 - Leeds and Northrup resistance decade box, 0 to 1000 ohm range.
R_2 - 20,000 ohm resistor.
R_3 - 150 ohm resistor
R_4 - 100 ohm Helipot potentiometer

FIGURE 1

F. Precautions

Adhere strictly to the procedure as outlined to obtain consistent and reliable results.

Reporting of Results

Report results on Form T-610.

REFERENCE

A California Method

End of Text on Calif. 642-A

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ORIGINAL REFLECTANCE VALUES FOR ALL REFLECTIVE LICENSE PLATES TESTED

Description	Candle Power/Foot Candle/Plate (Specific Intensity) 0°	10°	20°	30°	40°
Reflective Sheeting					
Nonrefl. black legend w/refl. white background:	17.6	17.6	15.6	12.9	9.8
Same (wet):	18.7				
Refl. green legend w/refl. white background:	18.4	17.6	16.0	13.3	9.8
Same (wet):	18.4				
Refl. blue legend w/refl. white background:	18.4	17.6	15.6	13.3	10.2
Same (wet):	18.4				
Nonrefl. black legend w/refl. yellow background:	13.3	12.5	10.9	9.0	6.6
Same (wet):	13.3				
Refl. white legend w/nonrefl. black background:	3.1	2.7	2.3	2.0	1.2
Same (wet):	3.5				
Refl. white legend w/refl. green background:	5.9	5.1	4.3	3.5	2.3
Same (wet):	5.9				
Refl. white legend w/refl. blue background:	3.5	3.1	2.7	2.0	1.2
Same (wet):	3.5				
Refl. yellow legend w/nonrefl. black background:	2.3	2.0	2.0	1.6	1.2
Same (wet):	2.3				

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Description	Candle Power/Foot Candle/Plate (Specific Intensity) 0°	10°	20°	30°	40°
Exposed Beads*					
Nonrefl. black legend w/refl. white background:	7.0	6.6	5.5	4.3	3.9
Same (wet):	5.9				
Nonrefl. black legend (SAMPLE) w/refl. yellow background**:	2.34	2.34	1.95	1.56	1.56
Nonrefl. black legend (SAM123) w/refl. yellow background:	5.2	4.9	4.3	3.5	2.7
Refl. white legend w/nonrefl. black background:	less than 1.0 (too low for accurate measurements)				
Refl. yellow legend w/nonrefl. black background:	Same				

NOTES:

* Reflectance values for the samples with nonreflective blue or green backgrounds or legends are the same as those given for the samples with a nonreflective black background or legend.

** The standard SAM123 samples for this color combination did not arrive in time for photographic inclusion in this report. This nonstandard sample used in this report had been in test on this department's outdoor exposure racks for one year. As noted above, the reflectance of the new standard SAM123 sample is considerably higher.

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GENERAL INFORMATION - REFLECTORIZED LICENSE PLATE COSTS (Pairs)

Size of California Blanks 6-1/16" x 12-1/16" x .209"

Area in square inches 2 x 6.0625" x 12.0625" = 146.2578 sq.inches per pair
146.2578 ÷ 144 = 1.0157 sq.ft. per pair
Size of metal area each blank is cut from 12-5/16" x 6-3/16" x 2 = 12.3125" x 6.1875" x 2 = 152.3672 sq.inches.
152.3672 - 146.2578 = 6.1094 sq.inches
6.1094 ÷ 146.2578 = 4.17% blanking waste.

Weight of Metal and Price Per Pair of Plates

Aluminum (alodized or equal) of .032" thickness (20 gauge) 0.451 lbs.per solid square foot
Requirements per pair of blanks - 0.451 x 1.0157 = 4581 lbs.
Price per pound $ .35 x .4581 lbs. = $ .1603 per pair
Galvanized and phosphatized steel of .0202" (27 gauge) - 0.84375 lbs per solid square foot
Requirements per pair of blanks - 0.84375 x 1.0157 = 0.8570 lbs.
Price per pound $ .12475 x 0.8570 = $ .10691 per pair

Size and Cost of Enclosed Lens Reflective Sheeting - Five Year

On plate 6-1/16" x 12-1/16" = 1.0157 sq.ft. per pair
Size of area sheeting is cut from 12-1/8" x 6-3/16" = 150.04 sq.in. pair
150.04 sq.inches - 146.2578 = 3.7822 sq.inches
3.7822 ÷ 146.2578 = 2.58% blanking waste

Five year enclosed reflective sheeting of other than white color $.52 per square foot. In 60,000 sq.ft. minimum quantities. Dipping clear is furnished with reflective sheeting and included in price.
Cost per pair for five year issue
1.0157 sq.ft. x $ .52 = $ .5282 per pair

Size and Cost of Exposed Lens Reflective Sheeting - Ten Year

On plate 6-1/16" x 12-1/16" = 1.0157 sq.ft. per pair
Size of area sheeting is cut from 12-1/8" x 6-3/16" = 150.04 sq.in pair
150.04 sq.inches - 146.2578 = 3.7822 sq.inches
3.7822 ÷ 146.2578 = 2.58% blanking waste

Price of exposed lens reflective sheeting is $ .55533 per square foot.

Cost per pair for ten year issue
1.0157 sq.ft. x $ .55533 = $ .56405 per pair

Equipment Cost

Estimated maximum for three lines $33,800.
This equipment should provide satisfactory service for three five year issues.

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Per Pair Cost of Reflectorized Five Year Plates

	Steel	Aluminum
Metal	$ .10691	$ .16030
Waste 4.17% blanking plus 0.5% other - 4.67%	.00499	.00750
Reflective Sheeting (5 year enclosed lens type)	.52820	.52820
Waste 2.58% blanking plus 0.5% other - 3.08%	.01630	.01630
Paint: roller-coater	.00124	.00124
Thinner	.00028	.00028
Newsprint	.00034	.00034
Envelopes	.00544	.00544
Cartons	.00240	.00240
Staples	.00012	.00012
Total Material	$ .66622	$ .72212
Plant overhead & burden	.05094	.05094
Engineering	.00060	.00060
Tooling	.00148	.00148
Equipment (new) depreciated over 3 five year issues	.00081	.00081
Sub-total	$ .72005	$ .77595
Contingencies @ 3%	.02160	.02333
Sub-total	$ .74165	$ .79928
Profit @ 5%	.03708	.03996
Total Cost Per Pair	$ .77873	$ .83924

Per Pair Cost of Current Five Year Painted Plates $ .22

Total Additional Cost Per Pair for Five Year Reflectorized Plates

Reflectorized five year plates	$ .77873	$ .83924
Current painted five year plates	$ .22000	.22000
Additional Cost	$ .55873	$ .61924

Average extra cost per pair per year

.55873 ÷ 5 =	.111746	
.61924 ÷ 5 =		.123848

Total Additional Cost for Entire Issue (13,800,000 pairs or 27,600,000 singles) for Five Year Reflectorized Plates

13,800,000 pair times $ .55873 =	$7,710,474	
13,800,000 pair times $ .61924 =		$8,545,512

Average total extra cost per year

$7,710,474 ÷ 5 =	$1,542,094,80	
$8,545,512 ÷ 5 =		$1,709,102.40

Total Cost for Entire Five Year Reflectorized Plate Issue

13,800,000 pairs (27,600,000 singles) @ $ .77873 per pair on steel equal	$10,746,474	
@ $ .83924 per pair on aluminum equal		$11,581,512

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