FINAL REPORT

EVALUATION OF PORTABLE RETROREFLECTOMETER FOR USE ON PAVEMENT MARKING MATERIALS

by

Frank D. Shepard
Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The subjective rating of the night visibility of pavement marking materials is difficult as it can be influenced by many variables. In an attempt to provide an improved method of determining the night visibility of these materials, a portable retroreflectometer was fabricated, and its precision and accuracy in determining night visibility were evaluated. It was concluded that the apparatus can be used to accurately measure the relative amount of reflected light for the entrance and observation angles built into it.

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Traffic markings are used extensively to provide the motorist roadway delineation and thus enhance traffic safety, especially during adverse weather conditions at night. Delineation techniques have also been used to provide guidance and regulatory information in the form of stop bars, crosswalks, pavement messages, etc.

Over the past several years the Department has conducted evaluations of pavement marking materials — namely, paints, thermoplastics, and preformed cold plastic tapes — and has developed a performance specification for the procurement of traffic paints. In all cases the evaluation of the marking materials has included determinations of the general appearance, durability, and night visibility. These qualities have been determined by subjectively rating them on a predetermined scale and combining the ratings in a formula to arrive at an overall rating. The general appearance and durability are relatively easy to rate; however, a subjective rating of the night visibility is more difficult, since it requires determining a value for the relative amount of light reflected. The subjective rating of night visibility has been questioned because it can be influenced by many variables such as the intensity and angle of the light source, external light sources, and the physical condition of the observer. Instrumentation is available that will give readings of light reflected from pavement marking materials; however, the apparatus is expensive, costing around $10,000, and is still being evaluated.

PURPOSE

Realizing the importance of improving upon the subjective method of evaluating the night visibility of pavement marking materials, the Research Council built a retroreflectometer, at a cost of approximately $250, for measuring the amount of light reflected from pavement marking materials. The purpose of this study was to evaluate the precision and accuracy of the Council-fabricated retroreflectometer in determining the night visibility of pavement marking materials.

DESCRIPTION OF APPARATUS

The retroreflectometer is a compact, portable device with a light source, battery, and photocell. The device can be used during the daytime by placing it directly on the material to be evaluated as pictured in Figure 1. Readings are taken using an entrance angle of 75° and a divergence angle of approximately 3°. The device is calibrated on a material with a known reflectance as a standard against which materials being tested can be compared. Although readings between materials are relative, they provide a basis for judging the night visibility of marking materials.

Figure 1. Retroreflectometer in use.

RESULTS

Samples

Forty-four samples of pavement marking material were obtained for test purposes. The samples, approximately 4 in. x 12 in., were applied to aluminum plates for observations of reflected light. The samples included the following variables:

- Beads on paint — regular beads (1.50 index) white and yellow paint
- Beads on paint — high index beads (1.90 index) white and yellow paint
- Preformed plastic tape — regular beads (1.50 index) white and yellow tape
- Preformed tape — high index beads (1.90 index) white and yellow tape
- Traffic paint — white and yellow

Approximately half of the samples were prepared in the laboratory and the remainder were taken from "on the road" machine painting done in conjunction with an evaluation of the performance of paint.

Precision

The precision of the retroreflectometer was evaluated by performing repeat tests on seven samples. Thirty readings were taken for each sample with intervals of 5, 10, 15, and 20 seconds between each reading. Table 1 gives the average reading and standard deviation for each category. Results show the precision to be good with minimal differences in the averages and standard deviations, regardless of the interval between sample readings.

A series of readings were taken on the sample being used as a calibration standard in an attempt to investigate the influence of the time interval between sets of readings, in addition to observing the influence of the readings during the initial or warm-up period.

Table 1

Precision for Different Reading Intervals

Sample	Interval Between Readings							
	5 Seconds		10 Seconds		15 Seconds		20 Seconds	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
White beads on paint (1.50 index)	163.9	0.20	163.7	0.55	163.0	0.29	163.1	0.36
White beads on paint (1.90 index)	182.0	0.46	183.2	0.39	182.9	0.29	183.0	0.19
Yellow beads on paint (1.50 index)	168.4	0.28	169.0	0.54	168.6	0.40	168.5	0.10
Yellow beads on paint (1.50 index)	162.2	0.73	162.8	0.54	162.5	0.52	162.5	0.23
Yellow preformed tape (1.90 index)	167.6	0.24	168.5	0.30	167.8	0.10	167.6	0.20
White paint	133.7	0.78	135.0	0.59	134.4	0.45	134.5	0.22
Yellow paint	120.5	0.86	121.73	1.09	122.49	1.06	120.4	0.74
	Avg.	0.51	Avg.	0.57	Avg.	0.44	Avg.	0.29

It is noted that the instrument does not need a warm-up; however, once the read button is pushed the light source causes a certain amount of temperature change. The influence of the time interval between sets of readings (30 readings per set) is given in Table 2. With the exception of the initial readings, for which no instrument warm-up was allowed, there were little differences in the averages and standard deviations. There was a slight decrease in the averages with time, which possibly resulted from the temperature rise created by the internal light being constantly turned on as the instrument was read.

It is noted that all readings were taken in the laboratory with a constant 74°F room temperature. It has been observed that, in some cases, readings taken in the field would rapidly decrease and stabilize at a number significantly below that initially observed. This was noted for both high and low temperature conditions. In an attempt to duplicate this decrease in the laboratory, readings were taken on a sample at different time intervals for three temperature conditions. Table 3, which gives the percentage decrease in readings for each condition, shows little difference in readings for each temperature. Since the steady decrease in readings was not duplicated in the laboratory, it can only be assumed that the decrease was not attributable to temperature variations.

Table 2

Influence of Time Intervals Between Readings

Time Between Readings in Each Set	Elapsed Time Between Sets: *Start Mean	*Start Std. Dev.	1 Minute Mean	1 Minute Std. Dev.	2 Minutes Mean	2 Minutes Std. Dev.	4 Minutes Mean	4 Minutes Std. Dev.	10 Minutes Mean	10 Minutes Std. Dev.	20 Minutes Mean	20 Minutes Std. Dev.
5 seconds	188.1	1.39	187.9	0.38	187.4	0.47	187.0	0.56	186.7	0.43	186.0	0.56
10 seconds	187.9	0.17	187.8	0.26	187.4	0.29	187.0	0.36	186.8	0.32	186.8	0.26
15 seconds	186.8	0.16	186.9	0.15	186.8	0.18	186.7	0.18	186.5	0.11	186.4	0.17

*Readings were started with instrument at room temperature.

Table 3

Percentage Decrease in Readings for Different Temperature Conditions

Temperature Condition	Elapsed Time — Seconds (Read button depressed): 30 Sec.	60 Sec.
Instrument and sample at room temperature — 74°F	1.0%	1.4%
Instrument at room temperature sample at 130°F	1.1%	1.8%
Instrument and sample at 130°F	1.0%	1.8%

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Accuracy

The ability of the retroreflectometer to measure the reflected light from pavement marking materials was determined by comparing readings obtained with those observed in the Department's light tunnel. It is noted that the Department's light tunnel and instrumentation are capable of accurately measuring retroreflection according to national standards. Light tunnel readings were taken at the angles shown in Table 4.

An entrance angle of 86° and observation angles of 0.2° and 0.5° correspond to those recommended by Federal Test Method Standard 370. The entrance angle of 75° and observation angle of 2.0° approximate, within the limits of the light tunnel's capabilities, those fixed angles built into the retroreflectometer.

Figures A-1 through A-16 of the Appendix are plots of the values of reflected light obtained from the samples as measured in the light tunnel versus those values found using the retroreflectometer for various sample categories and the divergence and entrance angles shown in Table 4. Curves representing the equations which best fit the observed points are also shown in the figures. Table 5 gives the correlation coefficients and curve equations for the plots.

The figures show a good correlation of the light tunnel vs. retroreflectometer readings for an observation angle of 2.0° and an entrance angle of 75° for all samples. These relationships are supported by the high correlation coefficients shown in Table 5. The curves and correlation coefficients for $0.2^{\circ}/86^{\circ}$ and $0.5^{\circ}/86^{\circ}$ show more scattering of points and correspondingly lower coefficients. One exception is the sample category with 1.90 high index beads and white paint, where correlation coefficients are high for all angles. It is noted, however, that only three samples were available for consideration; therefore, it was relatively easy to fit a curve and have high coefficients.

Table 4

Light Tunnel Angles Observed

Entrance Angle	Divergence Angle
86°	0.2°
86°	0.5°
75°	2.0°

Table 5

Curve Equation and Correlation
Coefficient for Each Sample Category

Sample Category	Angle Div./Ent.	Curve Equation	Coefficient of Correlation	Points Available
1.50 index beads on white paint	$0.2^\circ/86^\circ$	$Y = A(X^B)$	0.764	14
	$0.5^\circ/86^\circ$	$Y = A(X^B)$	0.744	14
	$2.0^\circ/75^\circ$	$Y = Ae^{BX}$	0.982	14
1.90 index beads on white paint	$0.2^\circ/86^\circ$	$Y = Ae^{BX}$	0.999	3
	$0.5^\circ/86^\circ$	$Y = X/(A + BX)$	0.999	3
	$2.0^\circ/75^\circ$	$Y = X/(A + BX)$	0.984	4
1.50 index beads on white tape	$0.2^\circ/86^\circ$	$Y = A(X^B)$	0.901	6
	$0.5^\circ/86^\circ$	$Y = A(X^B)$	0.902	6
	$2.0^\circ/75^\circ$	$Y = AE^{BX}$	0.997	6
1.50 index beads on yellow paint	$0.2^\circ/86^\circ$	$Y = A + (B/X)$	0.869	9
	$0.5^\circ/86^\circ$	$Y = A(X^B)$	0.864	9
	$2.0^\circ/75^\circ$	$Y = A(X^B)$	0.991	9
1.50 index beads on white paint and tape	$0.2^\circ/86^\circ$	$Y = A(X^B)$	0.833	20
	$0.5^\circ/86^\circ$	$Y = A(X^B)$	0.849	20
	$2.0^\circ/75^\circ$	$Y = Ae^{BX}$	0.986	20
1.90 index beads on yellow paint and tape	$0.2^\circ/86^\circ$	$Y = A(X^B)$	0.867	7
	$0.5^\circ/86^\circ$	$Y = A(X^B)$	0.880	7
	$2.0^\circ/75^\circ$	$Y = A(X^B)$	0.991	7

CONCLUSIONS

Based on the results on the evaluations, the following conclusions were drawn.

The precision was found to be good with small differences in the averages and standard deviations of the materials observed. The observed tendency for readings to decrease slightly with time, however, can be compensated for by adjusting the values based on frequent readings on the calibration standard. Also, it is suggested that when starting the readings, the read button be depressed several times to help stabilize the change in temperature caused by the interval light source. It is important that a calibration standard be read as often as necessary to monitor any differences in time, temperature, light, etc. Also, for the best results, the calibration standard should be kept in the same environment as the pavement markings being tested.

The reflectometer readings were found to correlate with the light tunnel readings at an observation angle of 2.0° and entrance angle of 75°. Therefore, it is believed that the instrument will accurately measure the relative amount of reflected light for those angles. The specific intensity per unit area of material may be found by using either the curve equations or graphs plotting the values of light tunnel readings versus retroreflectometer readings. The ability of the retroreflectometer to predict the amount of light reflected at observation angles of 0.2° and 0.5° and an entrance angle of 86° was poor, and it is recommended that the instrument not be used for these angles.

Based on limited field experience, the retroreflectometer seems to be sensitive to color differences that may result from variations in the pigments in the marking material or from traffic-related discoloration and dirt.

RECOMMENDATIONS

It is recommended that the retroreflectometer be used in determining the night visibility of pavement marking materials when the desired viewing angles are in the same range as those incorporated in the instrument. It is noted that the angles built into the retroreflectometer approximate those angles present when observing transverse pavement markings (right traffic lane) from the pavement shoulder.

Consideration should be given to the fabrication of an instrument simulating those angles as recommended by the Federal Test Method Standard 370. However, it is believed that the fabrication of another retroreflectometer should be postponed until a review can be made of the results of recently initiated investigations by ASTM and others relating the retroreflective characteristics of pavement marking materials and the associated geometrics of vehicle lights.

ACKNOWLEDGMENTS

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Special thanks are extended to J. E. Galloway, Jr., T. W. Neal, Jr., W. V. Mosley, Jr., and W. R. Baily III of the Materials Division for the use of the light tunnel facilities and for their assistance in data collection.

Also, appreciation is extended to Ed Walters of the General Services Administration for his consultation during this study.

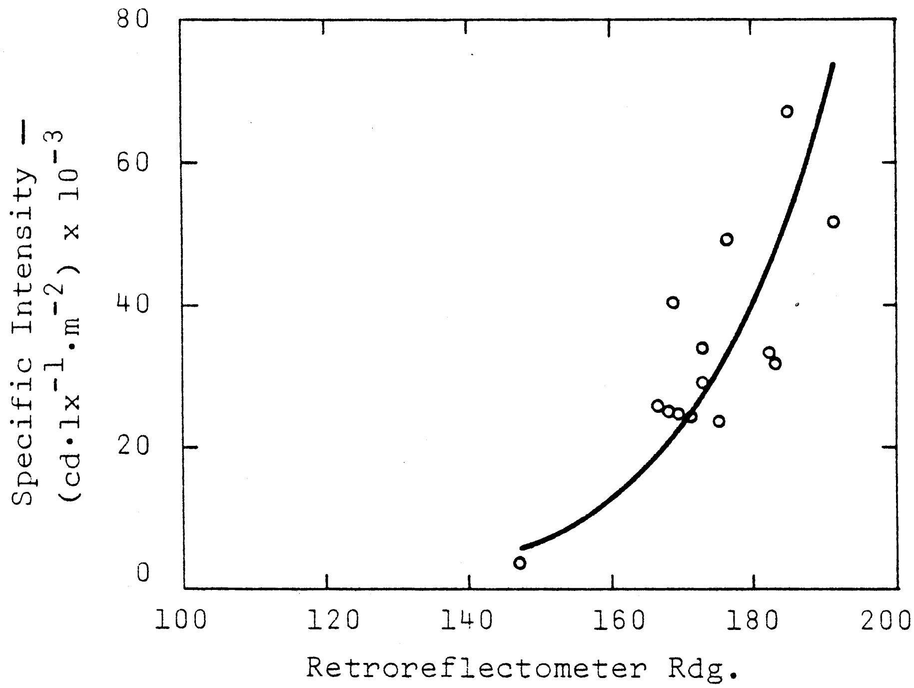

Figure A-1. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white paint — $0.2^{\circ}/86^{\circ}$.

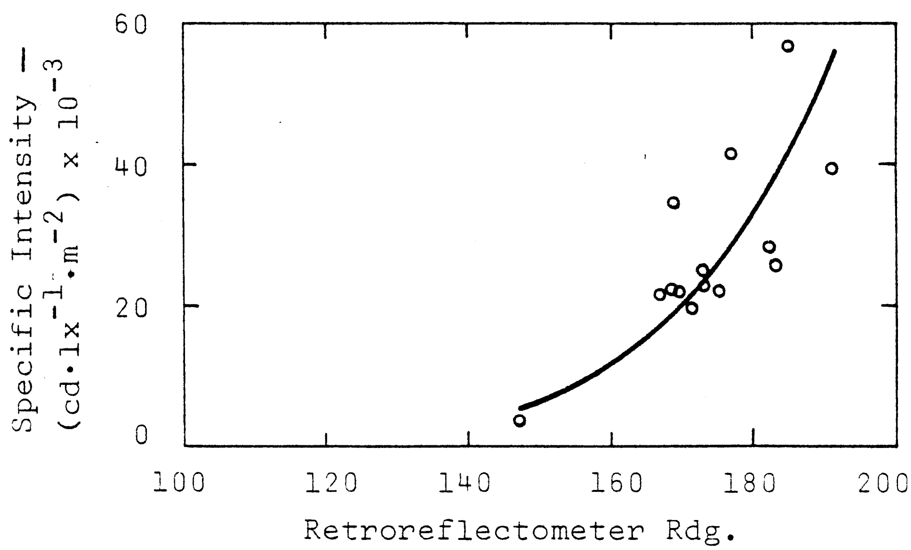

Figure A-2. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white paint — $0.5^{\circ}/86^{\circ}$.

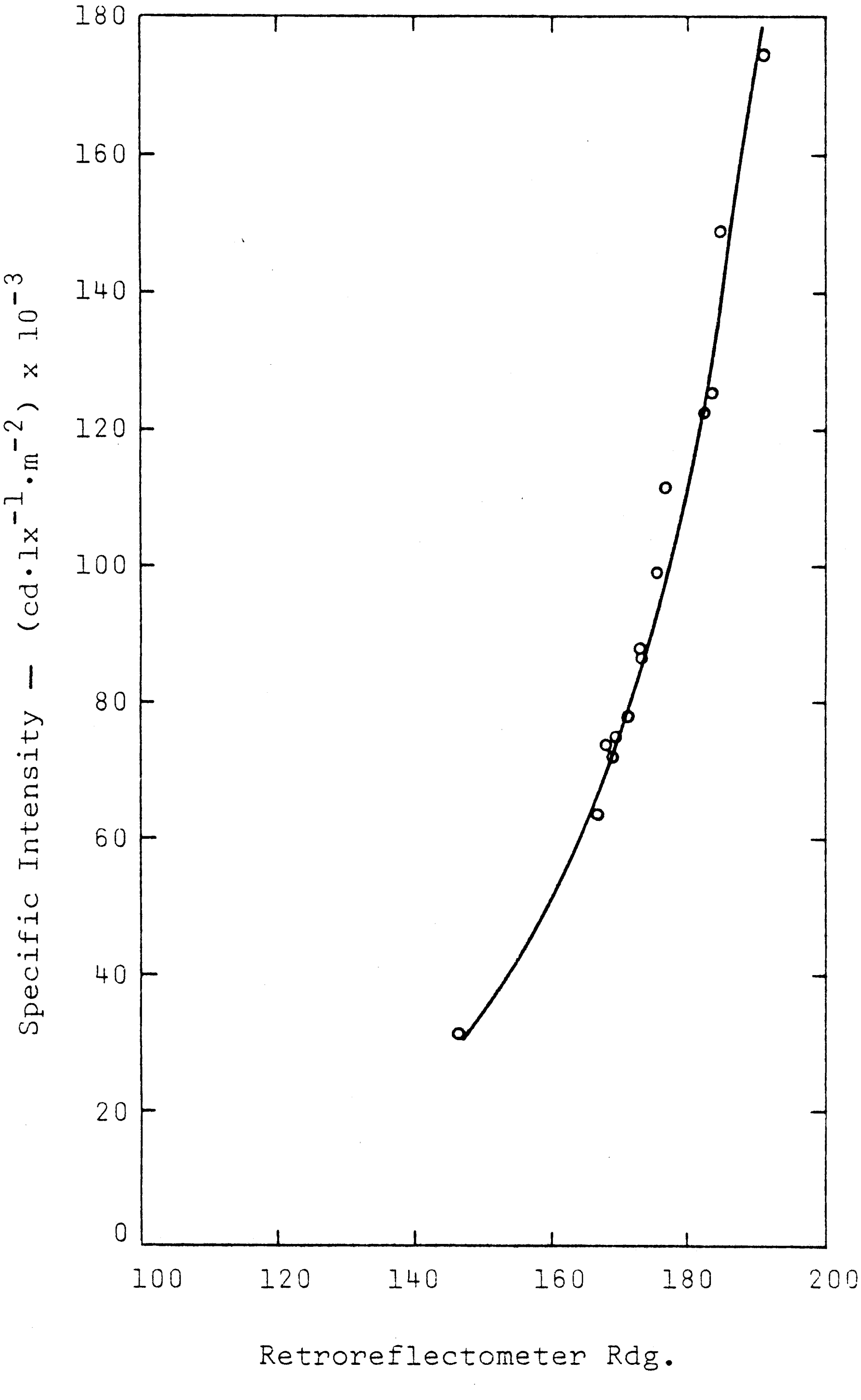

Figure A-3. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white paint — 2.0°/75°.

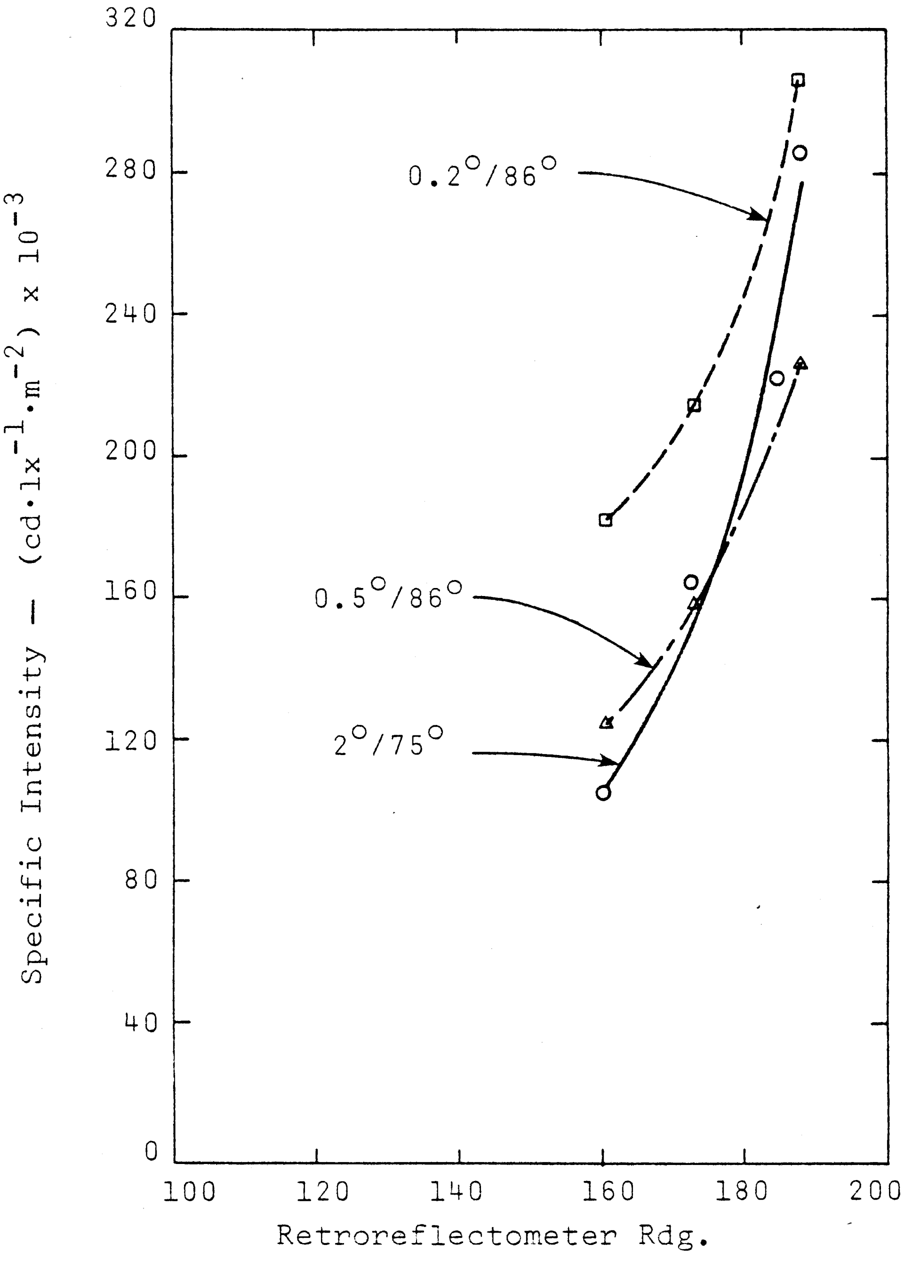

Figure A-4. Light tunnel reading vs. retroreflectometer reading — 1.90 index beads on white paint.

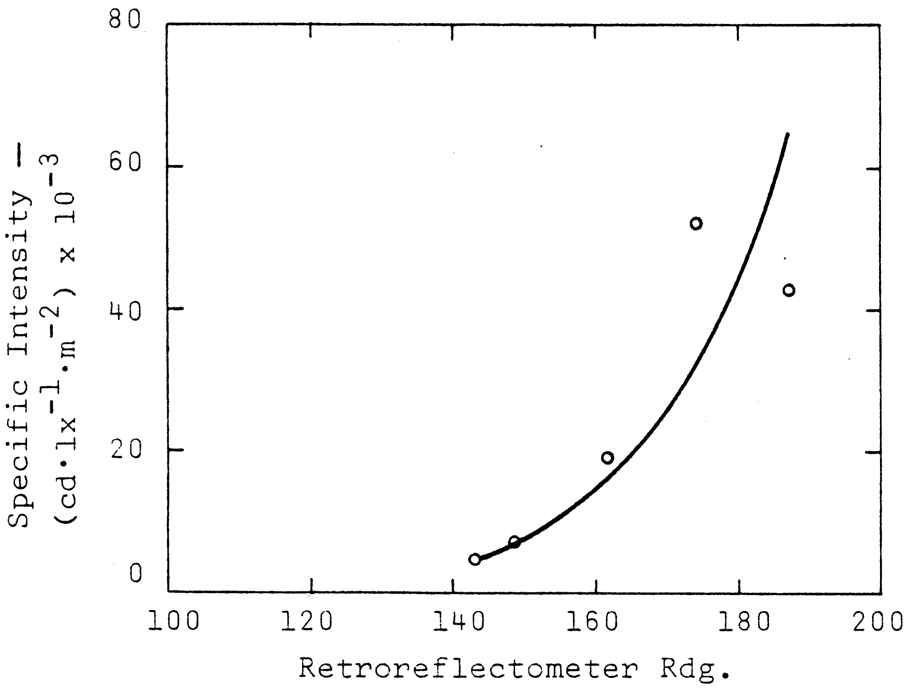

Figure A-5. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white tape — 0.2°/86°.

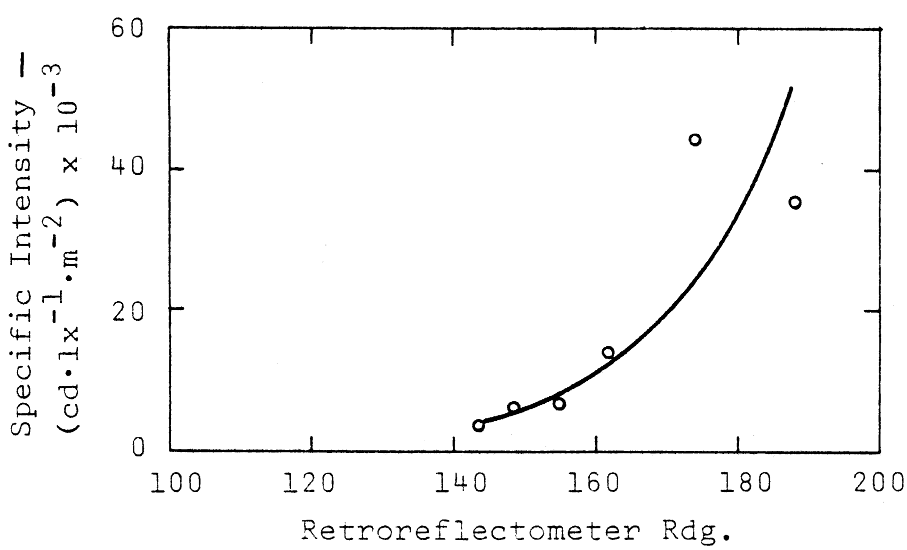

Figure A-6. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white tape — 0.5°/86°.

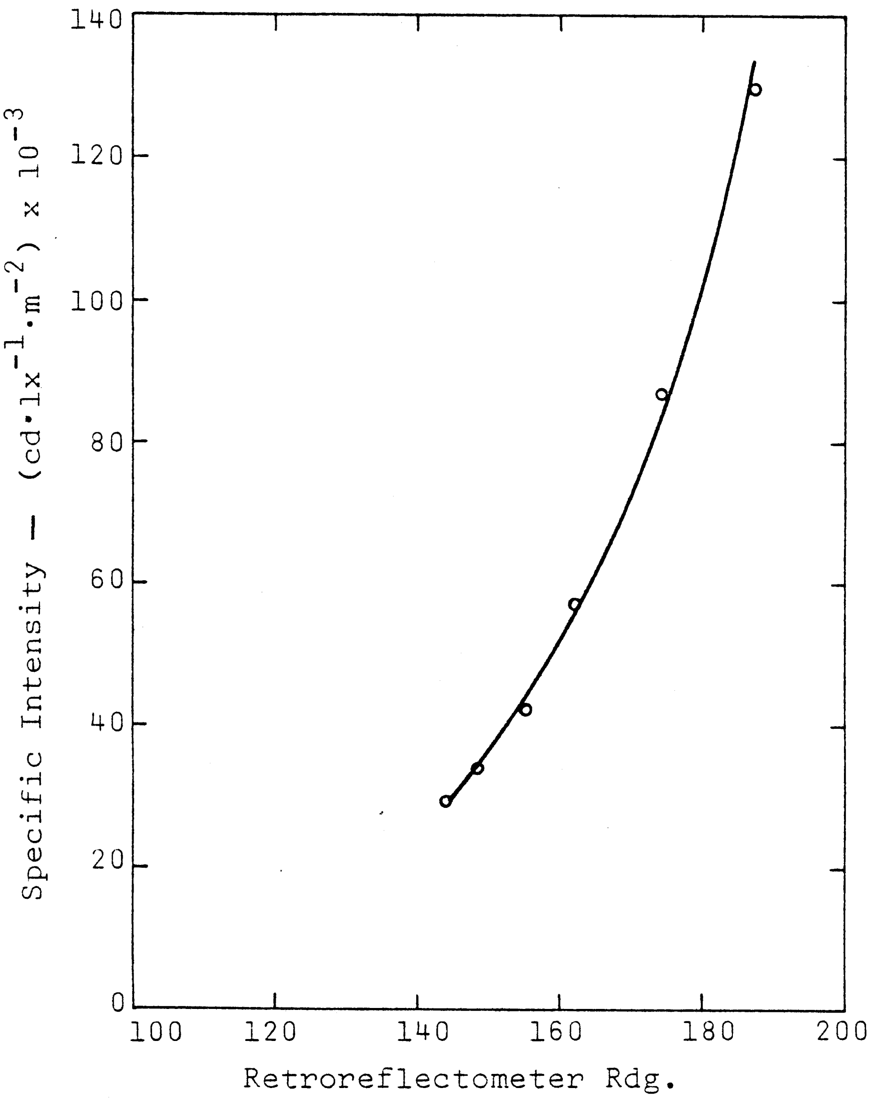

Figure A-7. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white tape — 2.0°/75°.

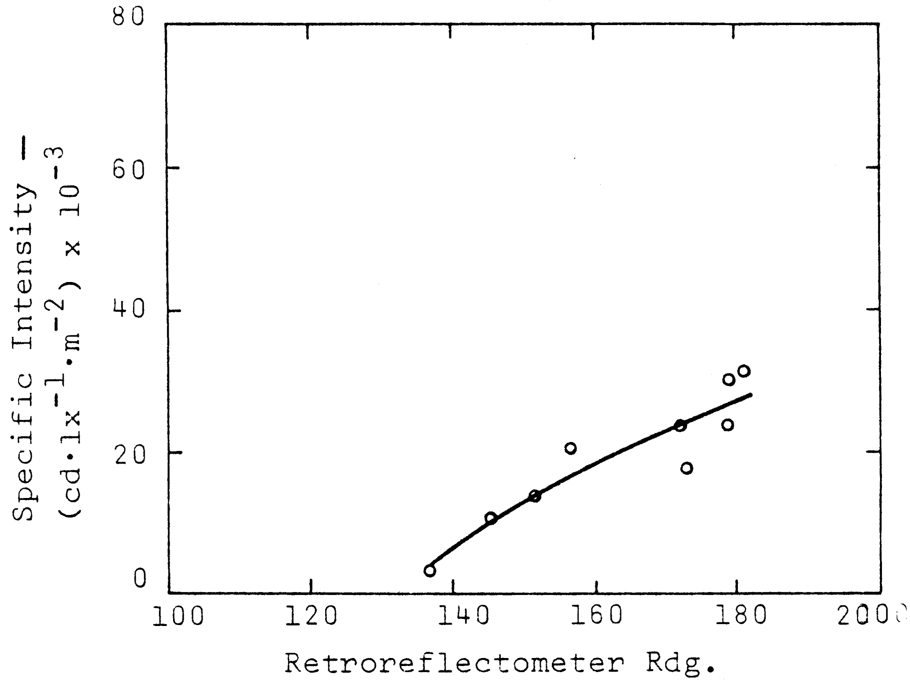

Figure A-8. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on yellow paint — $0.2^{\circ}/86^{\circ}$.

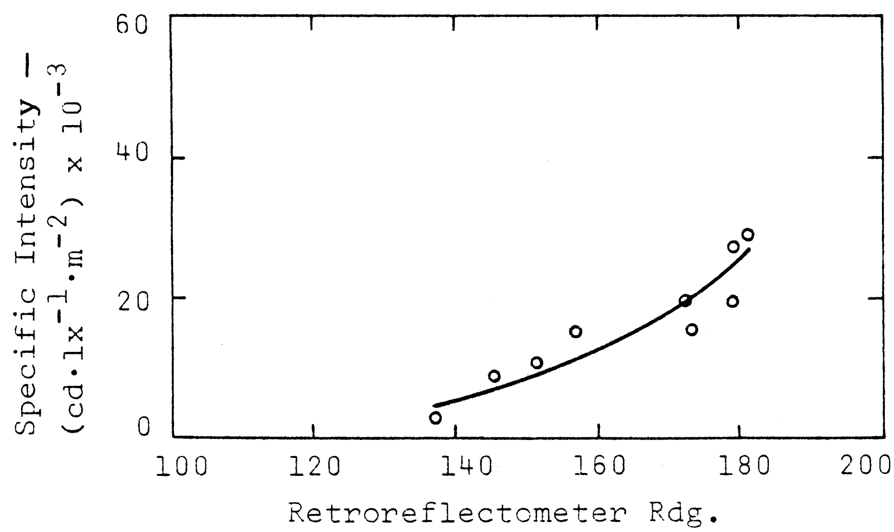

Figure A-9. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on yellow paint — $0.5^{\circ}/86^{\circ}$.

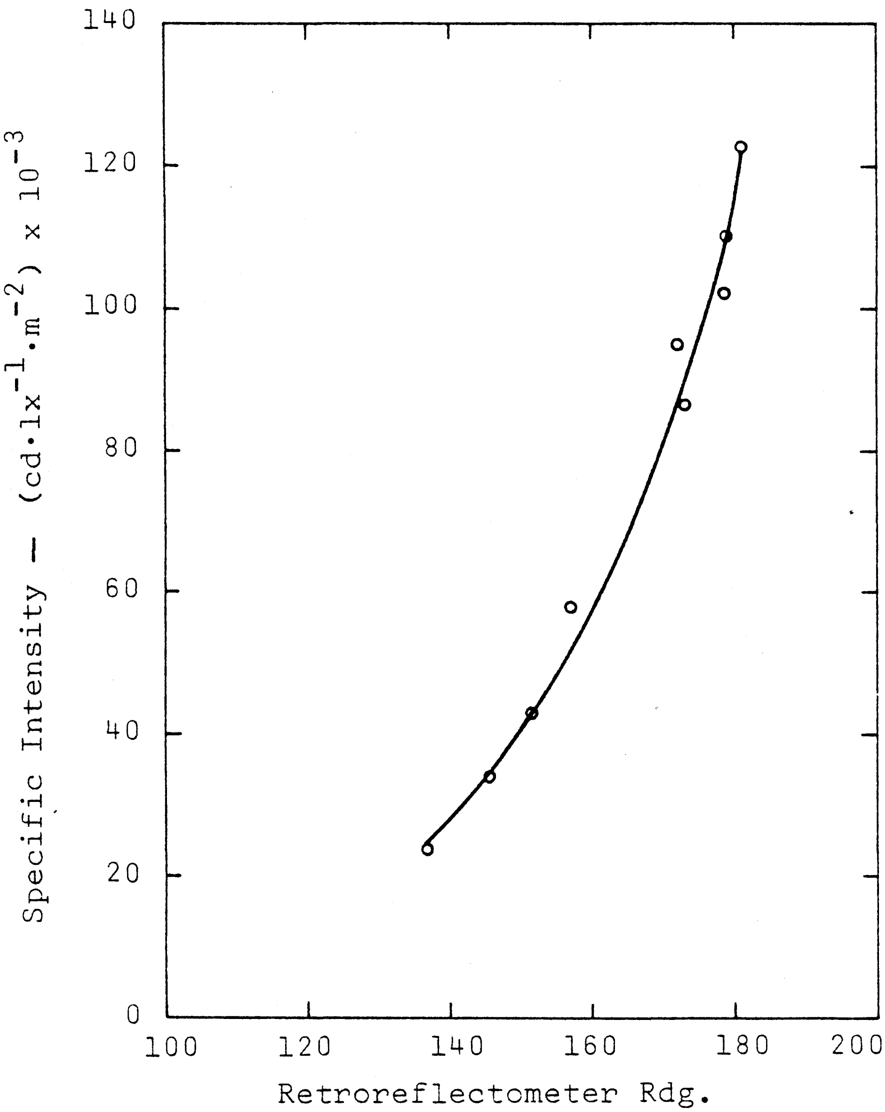

Figure A-10. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on yellow paint — $2.0^{\circ}/75^{\circ}$.

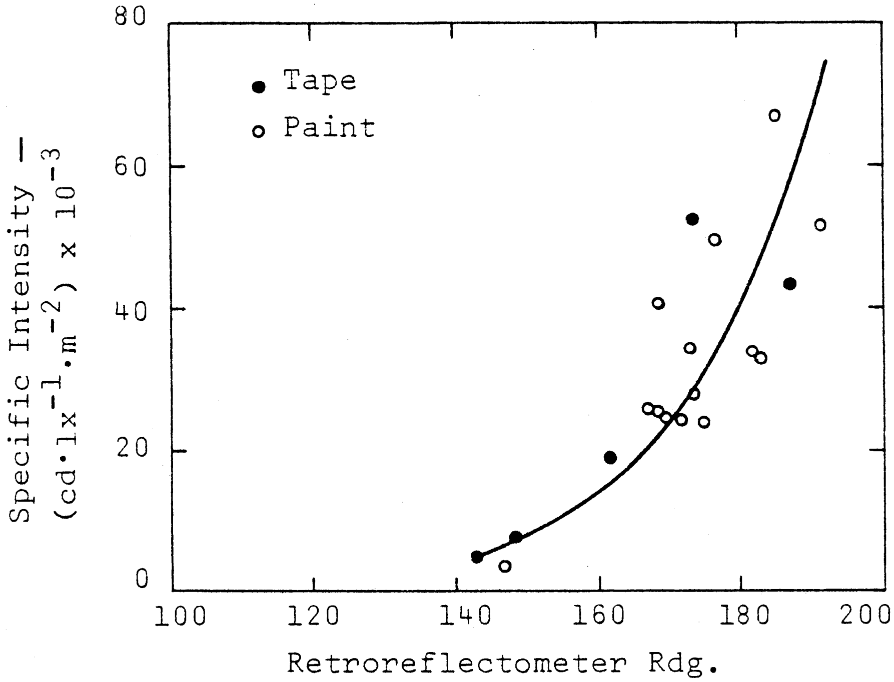

Figure A-11. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white paint and tape — 0.2°/86°.

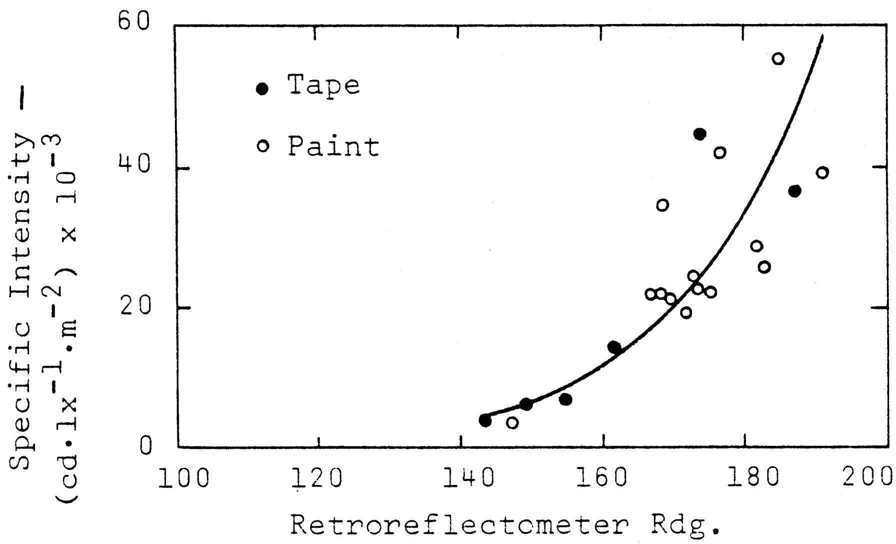

Figure A-12. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white paint and tape — 0.5°/86°.

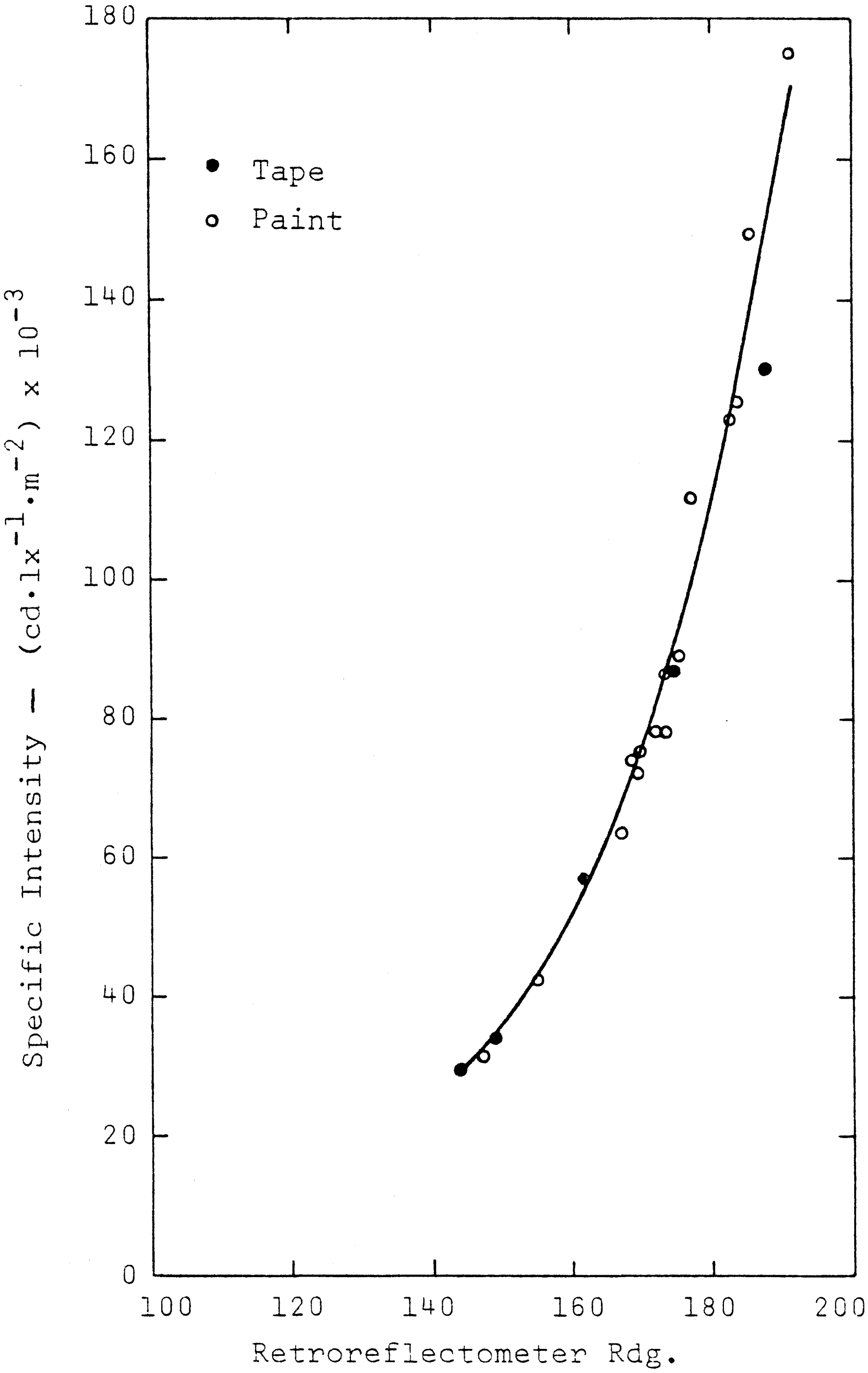

Figure A-13. Light tunnel reading vs. retroreflectometer reading — 1.50 index beads on white paint and tape — 2.0°/75°.

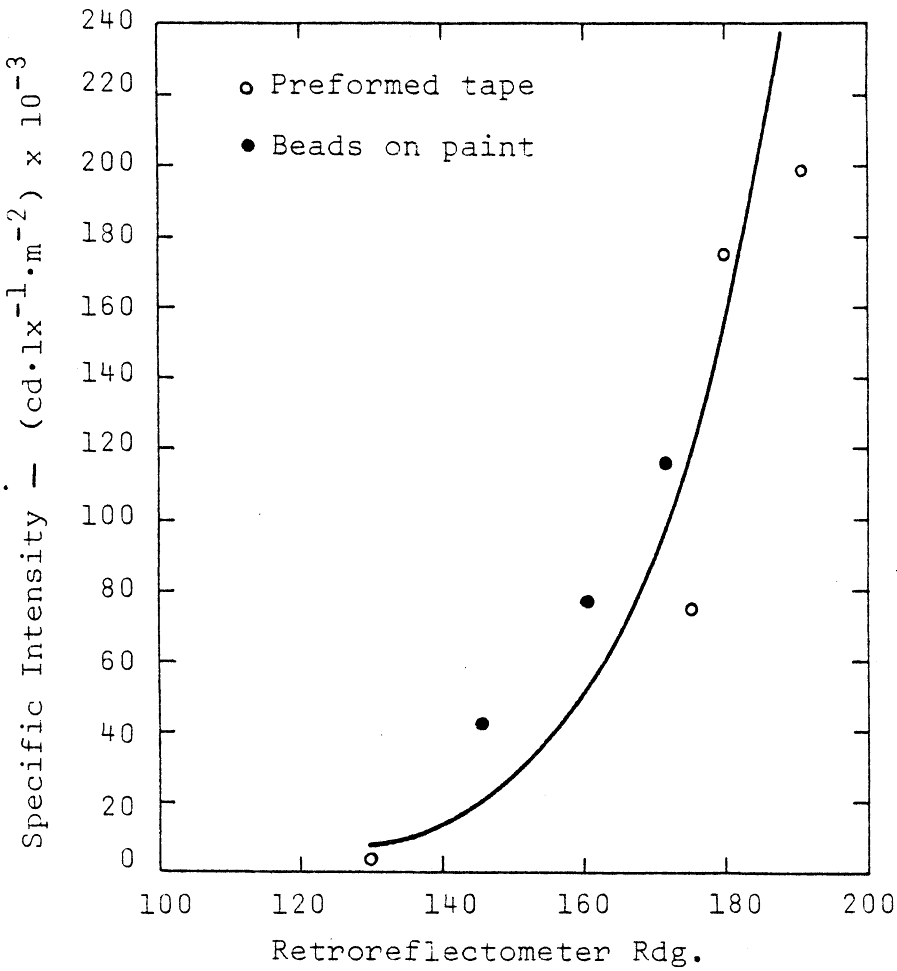

Figure A-14. Light tunnel reading vs. retroreflectometer reading — 1.90 index beads on yellow paint and tape — $0.2^{\circ}/86^{\circ}$.

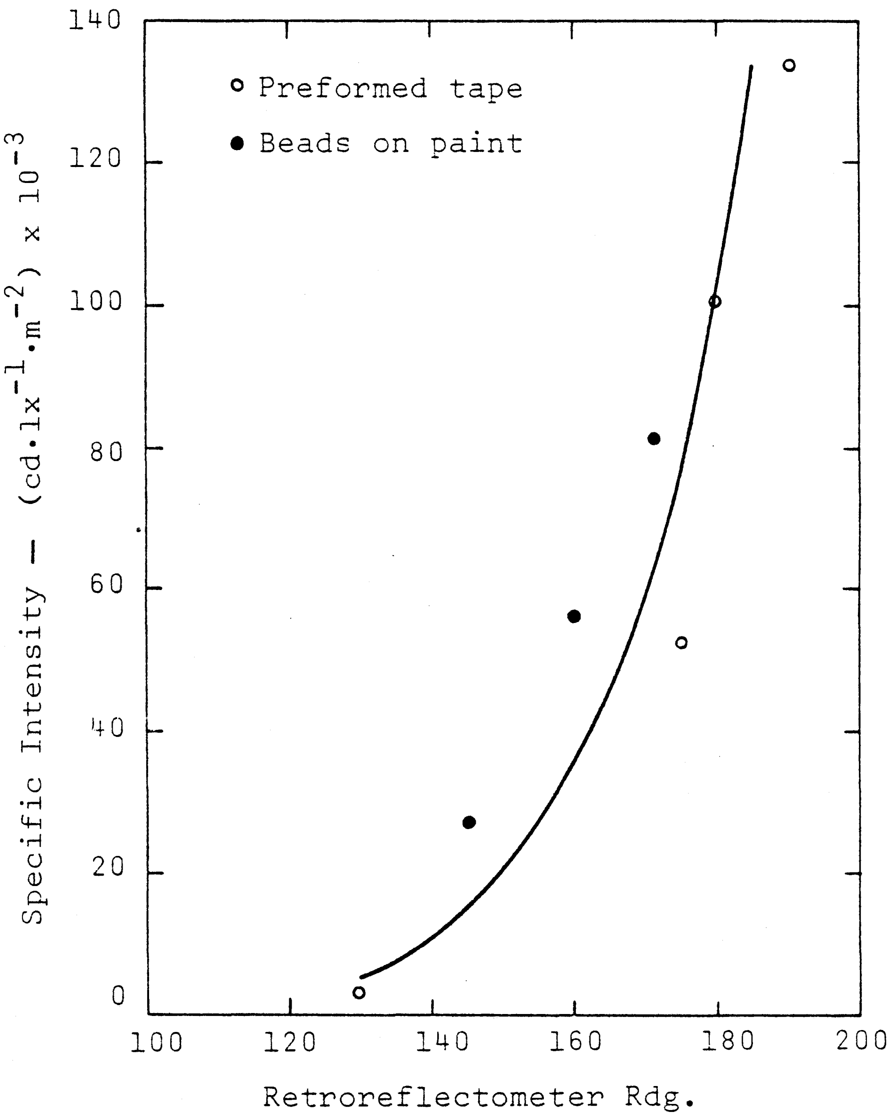

Figure A-15. Light tunnel reading vs. retroreflectometer reading — 1.90 index beads on yellow paint and tape — 0.5°/86°.

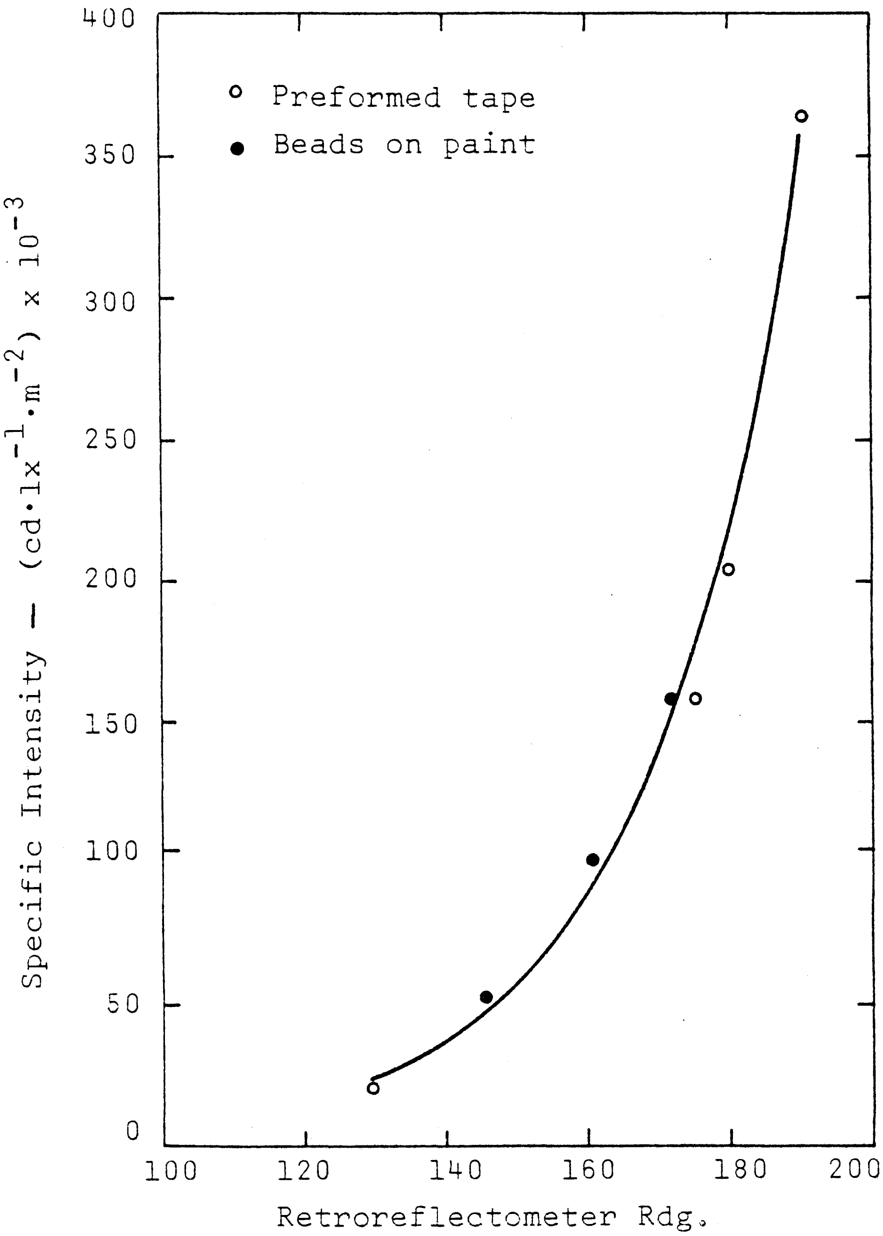

Figure A-16. Light tunnel reading vs. retroreflectometer reading — 1.90 index beads on yellow paint and tape — 2.0°/75°.