Deterioration of Retro-Reflective Sheet Under Outdoor Weathering and Weather-O-Meter

Dr. Surinder Mohan, Senior Principal Scientist, Dr. S. Gangopadhyay Director, Satyaveer Singh & Anjali Ahlawat, Research Interns,
Central Road Research Institute New Delhi
email: bhagat.surindermohan@gmail.com

ABSTRACT

More than one million road signs are installed over thousands of kilometers of highways in India. It is a matter of great concern that there is no strategy to assess their deterioration in terms of quality of retro reflective sheets under natural outdoor weathering and artificial accelerated weathering. The work reported in this paper is focused on how fast the deterioration of reflective sheets of different colors is occurring under natural weathering conditions in India. The deterioration is simulated with artificial weathering under Xenon-Arc chamber with known parameters of weather prevailing in India. This study will help in evaluating the performance of retro-reflective sheets in hours in weather-o-meter to same level of deterioration in the field in terms of days. Data for co-efficient of retro-reflectivity was collected for White, Yellow, Red, Orange, Green, and Blue Type III reflective sheets over a period of seven years in natural weather conditions of Delhi.

The best-fit curves technique was adopted to predict the life of retro reflective sheets of different colors in terms of days/months to reach its minimum allowable level. The higher values of R^2 for all colors indicate that there is a strong relationship between deterioration and age of reflective sheets in terms exposure in months/days, similarly the R^2 values were also found high when the exposure was made in weather-o-meter for few hours. It means that weather conditions in weather-o-meter are exactly being stimulated with prevailing weather conditions in Delhi. The study concludes that over a period of seven years the deterioration of blue color sheet is maximum and deterioration of green color sheet is minimum. This conclusion is also evident from physical parameters such as appearance of signs installed in India. The signs with blue base normally need early replacement in comparison to the signs made out of green sheet for National Highways. The parameters, which were set in weather-o-meter, need the exposure of different

hours for different colors of sheets for achieving minimum allowable level of reflectivity as per ASTM standard. The tentative results indicate that reduction of retro reflectivity after 124 months outdoors could be achieved in 90 hours exposure in weather-o-meter. The deterioration varies from color to color and the exposure hours are different for different colours of sheets. This is due to difference in the properties of the pigments used in reflective sheets.

1. INTRODUCTION

India has embarked on a massive road development programmed which includes construction of high speed corridors like the six lane Mumbai-Pune expressway and the four lane Ahmedabad-Vadodara expressway which is designed for speeds of 120 Kmph. Golden quadrilateral, East-west corridors are tentatively designed for speeds above 100 Kmph. Similarly construction for up gradation of number of existing highways from two lane to four lane and four lane to six lane where the operating speed have gone up, is in prohress. A number of measures have been adopted to improve road safety on these high speed corridors especially for night time, for which visibility of traffic control devices such as signs, signals, markings, kerbings, traffic islands, and medians are improved by making them retro reflective and brighter in nature. The Retro reflective properties enable them to reflect back the incident light towards the driver's eye and the brightness or luminance of the object improves the visibility distance from hazards[2]. The factor that determines the magnitude of retro reflection is the coefficient of retro reflectivity of the device. Beside this there are other parameters such as legibility, contrast, luminance and dynamic visual acuity as well as the driver's ability of perceiving and processing information, determines the visibility of these devices on these high-speed corridors. It is not feasible for the driver to see the road ahead continuously. The minimum sampling rate of the human eye is once in every 5000 milliseconds, means that the eye will have only one sample at 14 m distance at the speed of 100 Kmph. The safest response time for an unexpected event for a young driver is taken as 3 seconds, which includes reading, decision making time and stopping time. Thus at 100 Kmph the driver has early warning distance of 84 meter from the hazard and had only 6 frames of the hazard in the span of 84 m distance. This risk will further increase as speed increases to 120 Kmph as early warning distance is only 100 m and the number of frames will also be less. Under such situations, the driver has to manage everything quickly with very little information in his mind. Keeping this in mind the early detection of the message from a longer distance can release the fatigue of the driver while travelling on high-speed corridors. The proper maintenance of road signs is the prime concern for improving safety as dirty and ageing signs lose visibility significantly. Beside this there is the reduction in reflectivity of the sheet due to natural weathering. The magnitude of this reduction depends on weather conditions prevailing in that area and fading of the pigment over the period of time. The important atmospheric factors are magnitude of solar radiation falling per unit area (irradiance) in that region, rain, dew and temperature. The quantum of ultraviolet radiations in solar spectrum makes the quality of the sheet deteriorate. The more is the absorption of UV radiations by the pigment of reflective sheet the more will be the oxidation of the

pigment and fading of the reflective sheet.

The purpose of this paper is to collect data on the deterioration of reflective sheets of six colors under real time exposure to the weather conditions prevailing in Delhi over a period of seven years. The real time exposure of sheets is simulated with artificial accelerated weathering conditions generated in Weather-O-Meter (Xenon Arc Chamber) in the laboratory for achieving same deterioration in terms of exposure in hours. The results of the study will help in predicting the useful life of various grades and type of sheets in hours in Weather-O-Meter equivalent to the exposure in years. The results of study will indicate the durability and quality of sheets, which will also help in preparing a replacement schedule of road signs under the prevailing environmental conditions of Delhi.

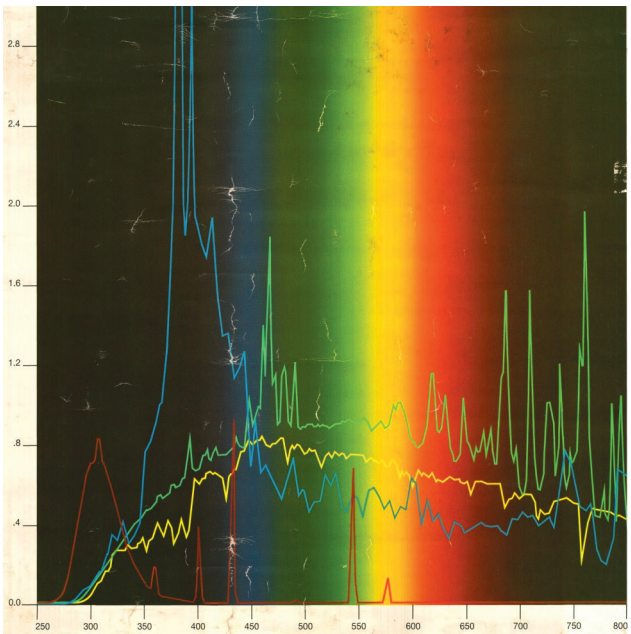
2. METHODOLOGY

The life of signs in terms of loss of retro reflectivity is determined by placing the six signs made out of reflective sheets of different colors in the environment of Delhi. The signs were placed facing southwards at an angle of 45º to horizontal. All the signs were made of High Intensity Grade Type III sheet. The samples of sheets of six different colors were also placed in weather-o-meter with known parameters of weather conditions. Coefficient of retro reflectivity of samples is measured before the start of experiment and then at regular intervals of time exposed in Weather-O-Meter and also under outdoor weathering. The useful life of samples is determined in terms of hours in weather-o-meter and in terms of months in outdoor weathering. The data so obtained will help in simulating deterioration of reflectivity under outdoor weathering to artificial weathering in Weather-O-Meter.

3. SETTING-UP OF WEATHER-O-METER

The quality of any environmental parameter in weather-o-meter depends upon the type of lamp used and the spectral power distributed over visible and ultra-violet spectrum (Figure 1). The most commonly used lamps are Carbon Arc, Sunshine Carbon Arc, Xenon Arc lamp etc. In the present study Weather-O-Meter having Xenon Arc lamp was used. The spectral power distribution of Xenon Arc lamp when filtered simulates UV and visible solar radiations more closely to sunlight spectrum; nowadays this lamp is widely used for testing materials. Weather-O-Meter can be programmed so that desired amount of irradiance may fall over the sample and one can create a cycle of exposure of rain associated with desired humidity and temperature. For the present study Weather-O-Meter is being programmed so that irradiance of 550 W/m^2 radiations in the visible spectrum (290-500 nm) or its equivalent energy of 60 W/m^2 in UV spectrum (400nm) fall over the samples of reflective sheets. The instrument is programmed for exposing samples at 65ºC to 70ºC with 5 minutes dark cycle associated with rain at an interval of every 25 minutes, as per the atmospheric studies carried out by Metrological (Figure 2).Department of US, it was found that different parts of the world get different levels of radiation exposure per year. The solar radiations received by some typical places are given in Table 1.0 and India received radiation exposure of 170 Kly (Kilo Langley) and its equivalent exposure in the UV spectral range is 450 MJ/m^2/year (Mega

Joules/sq. meter/year)[3]. The same is taken for Delhi climate in this study. It is a well-established fact that it is UV ranges of solar radiation are which primarily responsible for the degradation of reflective Sheets. Therefore, the researchers for the evaluation of the material generally take measurements under UV radiations exposure. This experiment is designed to correlate the degradation of retro reflective sheet under outdoor weathering to accelerated weathering in laboratory.



X Axis = Wavelength in Nanometer, Y Axis = Watts per square Meter per Nanometer.
Sunlight Sunshine Carbon Arc Xenon Arc Lamp Fluorescent Sun Lamp

Figure 1: Spectral energy distribution of sunlight and artificial light source

Table 1: Radiant exposure data per year at various places around the world

Region\Unit	Langley (Ly)	300-3000 nm Joule/m^2	300-800 nm UV+Visible Joule/m^2	300-400 nm UV Joule/m^2	340 nm Joule/m^2
Florida	140 KLy	5850 MJ/m^2	3400 MJ/m^2	355 MJ/m^2	3.2 MJ/m^2
Arizona	190 KLy	8000 MJ/m^2	4600 MJ/m^2	485 MJ/m^2	4.4 MJ/m^2
Central Europe	85 KLy	3550 MJ/m^2	2050 MJ/m^2	215 MJ/m^2	1.9 MJ/m^2
Southern France	120 KLy	5000 MJ/m^2	2900 MJ/m^2	300 MJ/m^2	2.7 MJ/m^2
India	170 KLy	7157 MJ/m^2	4115 MJ/m^2	434 MJ/m^2	3.9 MJ/m^2

Figure 2: Weather-O-Meter having xenon arc lamp.

3.1 Out Door Weathering

3.1.1 Preparation of Test Panels

Six test panels of size 2 × 2 feet^2 (0.3716 meter^2) were prepared by pasting type III reflective sheet of six colors viz., White, Blue, Green, Red, Yellow, and Orange on aluminum sheet. These test panels were installed at the height of 2 meters in the CRRI Campus in Delhi. These test panels were oriented at an angle of 45° from horizontal facing the equator as shown in figure 3. These panels were exposed under the climate of Delhi for seven years (84 months). The panels are washed cleaned before measurement.

Figure 3: Views of test panels for outdoors weathering.

3.2 Retro-Reflectivity Measurements

The co-efficient of retro reflectivity of test panels was measured at a regular interval of time of six months .The measurements were taken by using Reflecto meter Model 4500 at observation angle 0.2° and entrance angle -4°.The deterioration of retro-reflectivity with exposure of weather prevailing in Delhi for sheets of six colors is shown in Figures 4 and 5.The figures show that there is consistent reduction in reflectivity as the duration of exposure increases. The regression equation between the co-efficient of retro-reflection and deterioration of exposure was developed and has also been given in the figures 3 and 4 for each color .The trend line shows that there is strong relationship between reduction co-efficient of retro-reflection and exposure of deterioration for sheets for all colors as R^2 values are 0.9287, 0.9125, 0.9052, 0.7292, 0.7078, and 0.6594 for green, yellow, orange, white, blue, and red color sheets[4]. The percentage loss in co-efficient of retro-reflection of six colors over the period of seven years (84 month) under the outdoor exposure of Delhi conditions in given in table 1.1

The data indicates that the loss in retro reflectivity of blue color is maximum in the weather conditions prevailing in Delhi and is minimum for green color sheets .It could be due to this reason most of signs on National Highways are made with the sheet of green color followed by yellow color. It is also the most preferred color for signage as per international practice and signage's like Parking, Hospital etc. are made of blue sheet as most parking places in most countries are in the shade where exposure to the sun's radiations are less, so the blue color sheet is used for parking sign.

Table 1.1 Percentage Loss in coefficient of Retro-reflectivity.

S. No.	Color of Sheet	Percentage Loss in Reflectivity at the end of seven Years (84 Months)
1	Green	10
2	Yellow	27
3	White	33
4	Orange	34
5	Red	41
6	Blue	61

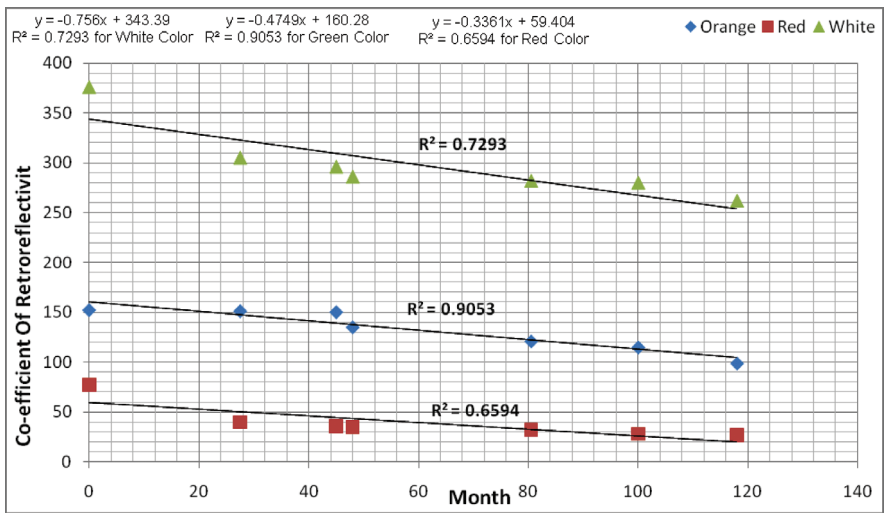


Figure 4: Deterioration of retro- reflectivity with age of reflective sheets

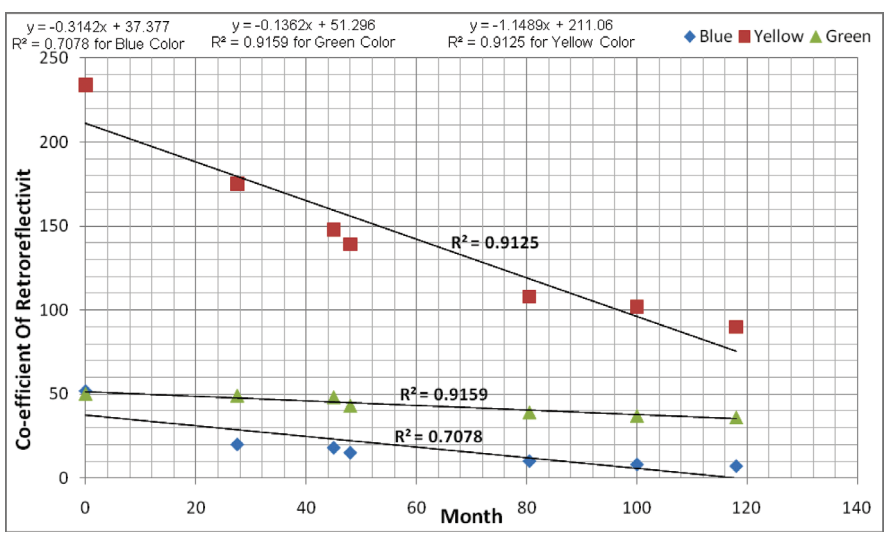


Figure 5: Deterioration of retro- reflectivity with age of reflective sheets

4.0 ARTIFICIAL WEATHERING IN WEATHER-O-METER

4.1 Preparation of samples

Reflective sheets of type III High Intensity grade sheet of six color, viz White, Green, Yellow, Blue, Red, and Orange were cut size of 13.5×4.5 cm^2 were placed in Weather-O-Meter. (Xenon Arc Lamp) for the duration of 345 hours .The artificial Weather-O-Meter was programmed as per the conditions explained ealier. The artificial conditions are similar to natural outdoor average weather conditions prevailing in Delhi over a period of twelve months. The samples were removed at regular intervals of time to measure the co-efficient of Retro-Reflectivity.

4.2 Retro-reflectivity Measurements

Co-efficient of retro-reflectivity of reflective sheets was measured at a regular interval of 50 hours of exposure in artificial weathering. The deterioration of Retro reflectivity with exposure in hours under artificial weathering conditions for six different colors has been shown in Figure 6 and Figure 7 The trend lines show that there is consistent reduction in co-efficient of reflectivity as the duration of exposure in artificial weathering increases the regression equation between co-efficient of retro reflection and duration of exposure was developed and has been given in the Figure 6 and 7 for six colors. The trend lines shows that there is a strong relationship between reductions in co-efficient of retro reflection and duration of exposure in hours for sheet of all six colors, R^2 values are 0.9306, 0.9274, 0.91152, 0.90923, 0.8876, and 0.8454 for Green, Yellow, Orange, White, Blue, and Red color respectively. The R^2 values are obtained for artificial Weathering and Outdoor Weathering are more less the same which means that the weather conditions created in Weather-O-Meter are similar to weather conditions prevailing in Delhi. The percentage loss in co-efficient of retro reflectivity at end of 384 hours of exposure is given in Table 1.3.

Table 1.2: Percentage loss of reflectivity under artificial weathering conditions

S. No.	Colors of Sheets	Percentage loss in co-efficient of retro reflection under artificial weathering
1	Blue	59
2	Red	58
3	White	49
4	Green	48
5	Yellow	37
6	Orange	33

The useful life of reflective sheets of different colors in terms of exposure under artificial Weathering is given in Table 1.3 .The Study reveals that different colors of sheet has its useful life different in terms of hours of exposure. It is due the behavior of pigment used for manufacturing the sheet.

The table shows that sheets of color Green, Blue, and White loss its useful life very early in comparison to sheets of colors Orange, Red, and Yellow.

Tables 1.3: Useful life different colors of sheets in terms of hours of exposure under artificial weathering.

S. No.	Colors of Sheets	Useful Life of Reflective Sheets in hours	Minimum Level of co-efficient of retro reflection Cd./Lx/m^2
1	Green	110	45
2	Yellow	320	170
3	White	290	250
4	Orange	396	100
5	Red	342	45
6	Blue	260	20

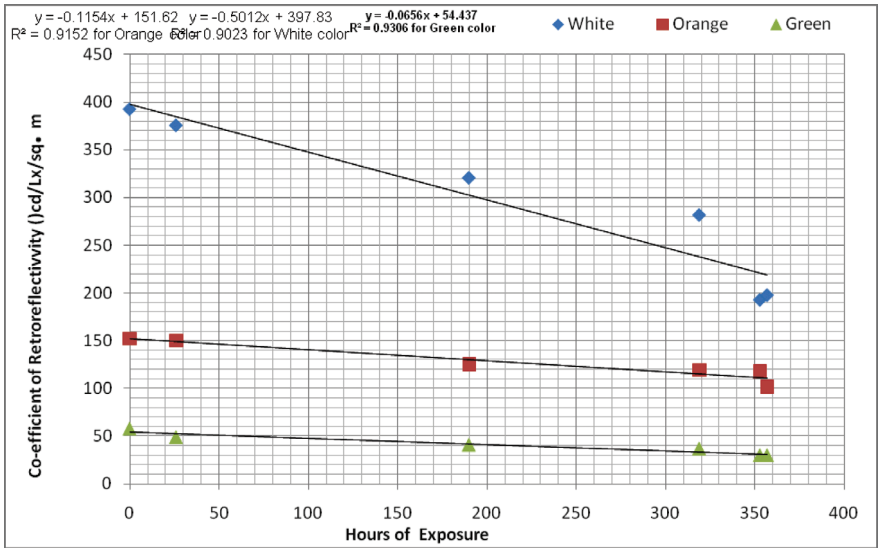


Figure 6: Deterioration of retro- reflectivity with age of reflective sheet

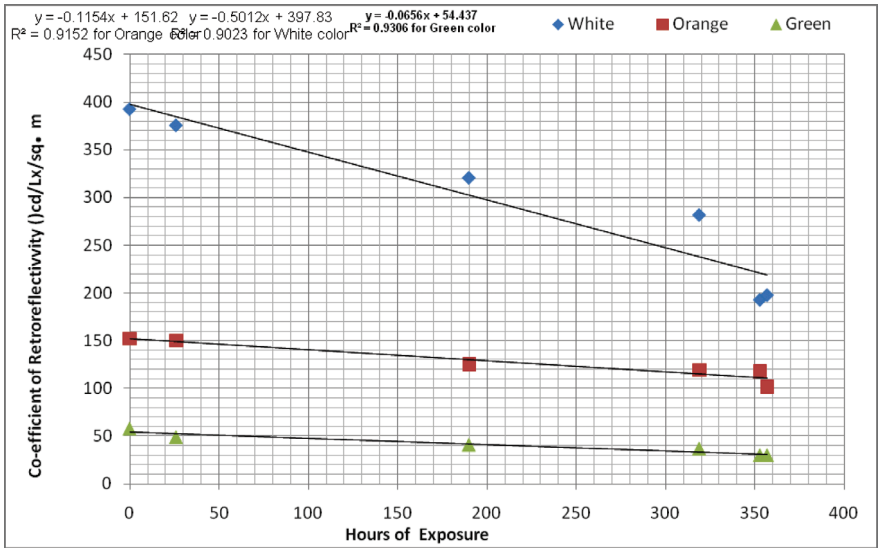


Figure 7: Deterioration of Retro- Reflectivity with Age of Reflective Sheet

5. ANALYSIS AND DISCUSSION

The durability or deterioration of retro reflective sheets was assessed under natural outdoor weathering and artificial controlled weathering. There is need to establish the relationship between outdoor weathering and artificial weathering for the climate of Delhi as earlier experiments were carried out with these sheets are in the climate of Florida, Arizona etc. in USA. The comparison of period exposure of sheets is limited to the useful life rendered by the sheets of different colors under two conditions as explained earlier. The useful life of sign is defined as the allowable value of co-efficient of retro reflectivity for different colors as ASTM standard.

Column one of the Table1.4 gives the values in hours for different colors of sheets under artificial weathering and for attaining the minimum co-efficient of retro reflectivity as given in column 3 of the same table. Column two of table1.4 given the values in days for different colors under natural weathering of reflective sheets for attaining the minimum level of co-efficient of retro reflectivity as given in column three of table 1.4

The study concludes that for Green sheets, 1500 days of exposure under natural weathering is equivalent to 110 hours of exposure under artificial weathering (Xenon arc Lamp) for reaching the minimum level of coefficient of retro reflectivity of 45 cd/lux/meter^2. Similarly for red sheets 3300 days of exposure is equivalent to 260 hours exposure in artificial weathering.

Table 1.4: Limiting duration under artificial and natural exposure.

S. No.	Color of Sheets	Duration of Exposure in hours under Artificial weathering	Duration of Exposure in days under natural weathering (Days)	Minimum Allowable level of co-efficient of Retro Reflection Cd/lux/meter^2
1	Green	110	50 X 30 = 1500	45
2	Blue	260	55 X 30 = 1650	20
3	White	290	120 X 30 = 3600	250
4	Yellow	320	35 X 30 = 1050	170
5	Red	342	42 X 30 = 1260	45
6	Orange	396	124 X 30 = 3720	100

Thus different colors of sheet require different hours of exposure under artificial weathering and corresponding to days of exposure under natural weathering under the climate of Delhi. These durations of exposure are different for achieving the same allowable level of co-efficient of Retro Reflectivity as given in the standard. Thus it is difficult to expose the each color for different hours in artificial weathering and thus all the color are to be exposed to maximum observed value which is 396 hours. The orange color sheet has taken maximum 396 hours under artificial weathering to reach its minimum level of co-efficient of retro reflectivity of 100 cd./lux/meter$^{2.}$ Therefore for checking the durability of reflective sheets it is necessary to expose the sheets for at least 400 hours under artificial weathering using Xenon arc lamp. As per international

practice also the minimum exposure of 480 hours is recommended for artificial weathering using Xenon arc chamber .The study concludes that 400 hours exposure under artificial weathering is equivalent to minimum 3000 days i.e. 8 years exposure of natural weathering under the climate of Delhi which is for Indian conditions.

6. CONCLUSION

In the present study efforts have been made to predict the deterioration of the co-efficient of retro reflectivity of different colors of sheet (White, Yellow, Red, Green, Blue, and Orange) with respect to exposure in months under outdoor weathering and hours in artificial weathering. The tentative curves on the basis of data collected for the climate of Delhi have been evolved. Analysis of data shows that R^2 vale are high for the trends lines between age and retro reflectivity. This means that climate conditions are responsible for deteriorating the reflectivity of all colors of sheets.

The purpose of this study is to find the durability limits for the reflective sheets through the exposure under natural weathering and artificial weathering. The approximate durability limit is to be as the duration of exposure till its deterioration reaches the minimum allowable value/useful life. The useful life of reflective sheets of six colors is estimated in terms of period in years of exposure up to which the sheet have the co-efficient of retro reflectivity above the minimum allowable level as prescribed in ASTM standard D4956 .The reflective sheet of orange color stands to maximum period of exposure of 124 months followed by white color sheet under the climate of Delhi. The tentative results indicate that under the climate of Delhi the sheet of color Yellow and red reach to its minimum allowable value within few months is not good for most yellow and red color sheets at 35 and 42 months respectively. Thus the deterioration of Yellow and Red color sheets is very fast under the climate of Delhi, which is much less in comparison to the orange color sheet. As there is practical difficulty in exposing the reflective sheets for such a long time of seven years in outdoor weathering therefore efforts have been made to find out equivalent hours of exposure required under artificial weathering for rendering useful service life till it attains the minimum allowable level of co-efficient retro reflectivity for different colors. The study concludes that 396 hours of exposure is required in the case of orange color sheet, 290 hours in case of white color sheet, 260 hours for blue color sheet, 110 hours for green sheet, 342 hours for red color sheet, and 320 hours for yellow color sheet are sufficient to judge the durability performance of sheets for 7 year durability performance under the outdoor natural weathering under the climate condition of Delhi. These results are limited to High Intensity grade type III Sheet and this study could be repeated for different type /grade of sheets under different climatic conditions prevailing in different parts of India.

7. ACKNOWLEDGEMENT

Authors are thankful to Dr. S. Gangopadhyay Director, CRRI for kind support and encouragement for allowing this paper to publication. Authors are thankful to M/S Alexis and M/S LG Chem India for providing logistics for our door weathering of reflective sheets. Authors are thankful to Dr. T.S. Ready and Mr. R. K. Bajpai Ex Scientist of CRRI for providing valuable guidance from time to time.

REFERENCES

1. ASTM Standard Specification for Retro Reflection Sheeting for Traffic Control ASTM D4956-09.
2. Surinder Mohan & Gangopadhyay (2011), "Night Time Road Safety Enhancement due to Visibility of Retro Reflective Road Sign". *International Seminar on national Road Safety,* New Delhi, March 2011.
3. Report on "Evaluation of Durability of Reflectivity of Reflective Sheeting Based on Results of the EMMIAQUA Test" Seibu Polymer Chemical Company Tokyo Company October 1997.
4. Venkata Pavan K. Immaneni, Joseph E. Hummer et.al., "Synthesis of signs Deterioration Rates across the US", Department of Civil Construction and Environmental Engineering North Carolina, State University US November 2002.
5. Surinder Mohan, M. Dutta and Bajpai R.K. (2004) "Evaluation of Visibility level of Retro Reflective Road Sign" *Indian Highways* Volume 32 March 41-49.