Degradation of the retroreflectivity and diffuse illumination of thermoplastic pavement markings: a case study in Thailand

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Abstract. Pavement marking is an essential task of road construction and maintenance. Pavement markings are beneficial because they provide information regarding the road alignment and road conditions ahead. To fully utilize their benefits, the retroreflectivity (RL₃₀) and diffuse illumination (QD₃₀) of pavement markings need to be above a minimum threshold. The degradation of RL₃₀ and QD₃₀ depends on several factors, such as the traffic exposure, age of the pavement marking, and weather. This research investigated the reflective efficiency of thermoplastics on an asphaltic concrete pavement marking with a glass bead rate of 359 to 553 grams per square meter. The reflective data were collected at the beginning of a period of eight months at two-week intervals. The factors that have a statistically significant effect on the pavement marking RL₃₀ and QD₃₀ include the traffic exposure and pavement marking position. The dirt coating on top of the marking is the most crucial factor that temporarily deteriorates the retroreflectivity, which can recover to some degree by rainfall.

1. Introduction

Pavement marking provides information to road users regarding their travel lane and upcoming changes in the roadway geometry [10]. Therefore, the visibility of pavement markings is essential, especially at night or in unlighted conditions. The visibility of pavement markings at night may be measured by the reflected brightness or retroreflectivity, whereas the visibility of pavement markings during the day time may be measured by diffuse illumination. Glass beads are dropped onto the thermoplastic paint while the marking is still wet to enhance the retroreflectivity of the marking. The addition of glass beads enhances pavement marking retroreflectivity, making them conspicuous at night with a small amount of headlight illumination [2]. The proper glass bead rate dropped onto pavement markings may increase retroreflectivity performance and service life. Service life is the time taken by a newly placed thermoplastic pavement marking to degrade to a predetermined minimum retroreflectivity level below which motorists would find it difficult to navigate on the roadway under night-time and poor visibility conditions [4]. To predict the service life of a pavement marking within its service environment, the factors that affect the service life of pavement markings need to be studied. The factors that affect the degradation of the retroreflectivity (RL₃₀) and diffuse illumination (QD₃₀) include the initial retroreflectivity, rainfall, positions of the pavement marking, shoulder, edge, or transverse rumble strips that are exposed to traffic to different degrees.
2. Literature Review

The retroreflectivity degradation of pavement markings may be influenced by several factors, such as traffic exposure, pavement marking position (edge line, lane dividing line, transverse rumble strips), initial retroreflectivity, and glass bead drop-on rate. Several studies have investigated factors affecting the degradation retroreflectivity of pavement marking and degradation models. Significant factors that affect retroreflectivity are the initial retroreflectivity [7][3][11], age of marking [7][11][8], traffic exposure [7][5][1], AADT [11], heavy vehicle percentage, marking position [7][11], color of marking [11], and pavement type [14].

The Earlier Minnesota Department of Transportation uses 120 mcd/m²/lx as a minimum threshold for pavement marking management programs [9]. The minimum thresholds of acceptable retroreflectivity recommended by MUTCD [6] are 50 mcd/m²/lx and 100 mcd/m²/lx for posted speed limits of 35 mi/h (56.4 km/h) or greater and 70 mi/h (112.7 km/h) or greater, respectively. In Thailand, according to the Department of Rural Roads standard, the initial retroreflectivity of white thermoplastic pavement marking should not be less than 200 mcd/m²/lx and 130 mcd/m²/lx for the retroreflectivity and diffuse reflectivity, respectively. The minimum acceptable retroreflectivity and diffuse illumination are 100 mcd/m²/lx and 65 mcd/m²/lx, respectively.

3. Test Site and Data Collection

The test site of this study is four-lane, asphaltic concrete highway NB. 1002 (between highway no. 9 – Bann Nong Plao Ngay) from sta. 9+000 to sta. 9+200. The average daily traffic volume was 5,942 vehicles per day. The heavy vehicles were approximately 13% of the volume, and the PHF was 0.89. The thermoplastic paint used for pavement marking conforms with TIS. 542-2549 [12] ASTM D 4797, AASHTO T250, and TIS 542-2549, and glass bead type 2 conforms with TIS. 543-2550 [13], and ASTM D1155. The retroreflectometer Zehntner ZRM 601 3+, which is in accordance with ASTM E1710, ASTM E2177, ASTM E2302, and EN 1436, was used to measure retroreflectivity and diffuse illumination.

According to the Department of Rural Roads (DRR) [5], Thailand, the initial retroreflectivity, \( R_{L30} \), must be not less than 200 mcd./m.²/lx. Furthermore, the initial diffuse illumination, \( Q_{D30} \), must be not less than 130 mcd./m.²/lx. The retroreflectivity and diffuse illumination were measured just a few days after the painting concluded and every two weeks for eight months. The minimum sample size of each marking position, each glass bead drop-on rate, was at least 30 samples. Figure 1 shows the configuration of the test plot. Three types of white thermoplastic pavement markings tested included edge line marking, lane-dividing marking, and transverse rumble strips.

The glass bead drop-on rate was tested at three different values to study their effects on the retroreflectivity and diffuse illumination. The glass bead drop-on rates for edge line marking and lane dividing marking were 359, 435, and 467 g/m². For transverse rumble strips, the glass bead drop-on rates were 400, 508, and 553 g/m². The drop-on glass bead rate required by the DRR is 400 g/m².

![Figure 1. Configuration of the pavement marking tested.](attachment:image.png)
4. Findings

4.1 Initial Retroreflectivity and Diffuse Illumination of The Pavement Marking

Table 1 shows the marking position, glass bead drop-on rate, and initial value of the retroreflectivity and diffuse reflectivity. The minimum initial values of $R_{L30}$ and $Q_{D30}$ by the DRR in Thailand are 200 and 130 mcd./m$^2$/lx., respectively. With different glass bead drop-on rates, the average initial values of $Q_{D30}$ and $R_{L30}$ exceeded the standard, except for the transverse rumble strips in the right lane with a glass bead drop-on rate of 400 g/sq.m. The average initial $R_{L30}$ was only 180 mcd./m$^2$/lx. This result may be caused by the distribution, alignment, or sinking of different glass beads, which may be affected by external factors such as the wind and the temperature of the thermoplastic pavement marking. However, on the second measurement, fifteen days after the first measurement, the $R_{L30}$ increases to 248 mcd./m$^2$/lx., which is higher than the requirement by the DRR. This increase agrees with the study by NCHRP [10]. The retroreflectivity of newly placed pavement markings increases initially because the glass beads become exposed after some amount of wear and then peaks before reducing over time as the pavement markings wear out.

The data also show that a higher glass bead drop-on rate does not necessarily provide a higher initial value of $R_{L30}$. However, from this study, it may be concluded that the rate of glass beads of 359 grams per square meter is considered sufficient for the retroreflectivity ($R_{L30}$) to meet the minimum required value by the DRR. Moreover, applying glass beads at a rate of 400 g/m$^2$, as per the requirements of the DRR, is also usable.

Similar to $R_{L30}$, when the applied glass bead drop-on rate increases, the diffuse illumination ($Q_{D30}$) does not show a clear relationship pattern. The $Q_{D30}$ value is in the range from 136 - 215 mcd./m$^2$/lx., which is higher than 130 mcd./m$^2$/lx., the minimum threshold by the DRR. From this study, it can be concluded that the rate of glass beads (359 g/m$^2$) is considered sufficient for $Q_{D30}$ to meet the standard. Meanwhile, the glass bead drop-on rate of 400 grams per square meter is also appropriate. The ANOVA test also showed that there is no significant difference in $R_{L30}$ and $Q_{D30}$ with different glass bead drop-on rates at a 95% confidence level. The p-values are 0.279 and 0.064 for $R_{L30}$ and $Q_{D30}$, respectively.

Table 1. $Q_{D30}$ AND $R_{L30}$ at various glass bead drop-on rates.

| Marking position                          | Glass beads drop-on rate (g/sq.m.) | Sample Size | Average initial values (mcd./m$^2$/lx.) |
|------------------------------------------|------------------------------------|-------------|----------------------------------------|
| Edge line marking                        | 359(EL-359)                        | 31          | 208                                    | 263                                    |
|                                          | 435(EL-435)                        | 36          | 215                                    | 276                                    |
|                                          | 467(EL-467)                        | 37          | 215                                    | 264                                    |
|                                          | 359(DL-359)                        | 30          | 186                                    | 253                                    |
| Lane dividing marking                    | 435(DL-435)                        | 35          | 188                                    | 279                                    |
|                                          | 467(DL-467)                        | 45          | 194                                    | 260                                    |
| Transverse rumble strips (left lane)     | 400(TRS-L-400)                     | 60          | 193                                    | 254                                    |
|                                          | 508(TRS-L-508)                     | 60          | 200                                    | 299                                    |
|                                          | 553(TRS-L-553)                     | 60          | 192                                    | 271                                    |
| Transverse rumble strips (right lane)    | 400(TRS-R-400)                     | 60          | 136                                    | 180*                                   |
|                                          | 508(TRS-R-508)                     | 60          | 148                                    | 204                                    |
|                                          | 553(TRS-R-553)                     | 60          | 158                                    | 281                                    |

*Lower than DRR's standard

4.2 Degradation of The Retroreflectivity and Diffuse Illumination

Considering the glass bead drop-on rates applied on the surface, when a rate of 400 g/m$^2$ is used, according to the minimum threshold, a service life of approximately seven to eight months under prevailing conditions is demonstrated. The retroreflectivity is the parameter used to control the service
life of pavement markings. The temporary degradation caused by accumulated dirt and tire black can be recovered through cleaning either by rainfall or manual approaches. Figure 2 shows the $R_{L30}$ and $Q_{D30}$ of shoulder markings where dirt is usually present. After a few days of rainfall, the measurement on day 155 shows that the $R_{L30}$ and $Q_{D30}$ increased. It was also true for the lane dividing marking and transverse rumble strips on the left lane where the traffic was relatively low (Figure 3 and Figure 4). On the other hand, for the transverse rumble strips on the right lane where traffic volume was higher than those on the left lane; the value of $R_{L30}$ did not increase after the rainfall. This degradation is a result of permanent degradation caused by traffic passing over the markings.

Figure 2. $R_{L30}$ and $Q_{D30}$ of the edge line marking.

Figure 3. $R_{L30}$ and $Q_{D30}$ of the lane dividing marking.
4.3 Factors affecting the degradation of the retroreflectivity and diffuse illumination of the thermoplastic pavement marking

Multiple linear regressions were developed to find significant factors that affect the retroreflectivity and diffuse illumination. The factors that were considered were the initial retroreflectivity, initial diffuse illumination, age of marking, position of marking, AADT, traffic exposure, and rainfall. The factors that have a statistically significant effect on pavement marking retroreflectivity include the traffic exposure (AADT* Age of pavement marking) and the position of the pavement marking (lane dividing line, edge line, and transverse rumble strips), as shown in Table 2. As expected, the retroreflectivity deteriorates as traffic exposure increases. The positions of the pavement markings have a degree of impact on the retroreflectivity ranking from high to low as follows: lane dividing lines > transverse rumble strips > edge lines. The high degree of impact provides a positive correlation with the retroreflectivity. The edge line usually exhibits a temporary degradation of the retroreflectivity due to the dirt coating on the top of the marking.

For QD30, statistically significant factors are the traffic exposure (AADT*Age) and position of pavement marking, as shown in Table 3. Similar to the degradation of RL30, QD30 decreases as the traffic exposure increases. The position of the edge line pavement marking has a higher positive correlation to
than that of lane diving lines and transverse rumble strips. This result may be because it is exposed to less traffic.

### Table 2. Multiple linear regression of the model to predict $R_{L30}$.

| Model                | Unstandardized Coefficients | Standardized Coefficients | t     | Sig.  |
|----------------------|-----------------------------|---------------------------|-------|-------|
|                      | B              | Std. Error | Beta     |       |
| Constant             | 215.177        | 9.789       | 21.981   | <0.001|
| AADT*Age             | -1.8282×10^{-4}| 0.00         | -0.642   | -7.621| <0.001|
| Lane Dividing Line   | 136.485        | 15.249      | 0.746    | 8.951 | <0.001|
| TRS                  | 59.433         | 12.123      | 0.420    | 4.902 | <0.001|

where

- AADT*Age \(=\) AADT (veh/day) × Age of the pavement marking (days)
- Lane dividing line \(=\) 1 if the position of the pavement marking is the middle line; else = 0
- TRS \(=\) 1 if the position of the pavement marking is an edge line; else = 0
  if pavement marking is transverse rumble strips, then lane dividing line = 0 and TRS = 0

### Table 3. Multiple linear regression of the model to predict $Q_{D30}$.

| Model   | Unstandardized Coefficients | Standardized Coefficients | t     | Sig.  |
|---------|-----------------------------|---------------------------|-------|-------|
|         | B              | Std. Error | Beta     |       |
| Constant| 170.166         | 6.953       | 24.475   | <0.001|
| AADT*Age| -5.8910×10^{-5}| 0.000       | -0.502   | -4.890| <0.001|
| Edge Line | 16.255         | 5.466       | 0.305    | 2.974 | <0.001|

5. **Conclusion and Recommendations**

Although the DRR requires a glass bead drop-on rate of 400 g/m², the required initial $R_{L30}$ and $Q_{D30}$ values can also be met with a glass bead drop-on rate of 359 g/m². The glass bead drop-on rates between 359 and 400 g/m² can be used to provide the values of $R_{L30}$ and $Q_{D30}$ that meet the minimum requirement. The factors that have a statistically significant effect on the pavement marking $R_{L30}$ and $Q_{D30}$ include the traffic exposure (AADT × Age of marking) and the position of pavement marking. Temporary degradation caused by dirt or tire black marks can be improved by a cleaning process. Recommendations for future studies include replication tests in other road classes and pavement types.

**Acknowledgement**

The authors are grateful for the financial support from the faculty of engineering, King Mongkut's University of Technology North Bangkok, Thailand.

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