High performance thermoplastic and cold applied plastic road markings: how long do they last?

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Abstract. The function of road markings is to provide guidance and warnings to motorists. These markings should be clearly visible at all times. It is empirical that the materials used should be durable especially on roads with heavy traffic to ensure that the safety and comfort of motorists are not compromised at all times, and to avoid the need to repaint regularly which is cumbersome and requires a significant amount of funds. This paper highlights some good and bad practices in laying the road markings which result in satisfactory and poor performances respectively. Field trials have been carried out using thermoplastic and cold applied plastic produced and installed by various applicators. Various factors which could possibly affect the brightness and durability of the road markings such as the quality of the inter-mix and drop-on reflective beads, different techniques in incorporating the drop-on reflective beads, variation in the laying temperature and thickness of the road markings, and the conditions of the road surface during laying, are discussed. Test results have shown that cold applied plastic provides higher retro-reflectivity than thermoplastic after four years which indicates that the former type could hold the reflective beads more firmly.

1. Introduction
Thermoplastic road markings will appear bright and glowing after installation. The ability to reflect light from vehicles’ headlamps at night could help motorists to see clearly the road markings, and thus feel safe and comfortable. However, when it rains, conventional glass beads could not reflect light effectively when submerged in thin film of water on the road surface, resulting in the road markings appear dull and difficult to see. Consequently, all-weather thermoplastic (AWT) or high performance thermoplastic road markings have been introduced and included in the new specification of Public Works Department (PWD) Standard Specification for Road Works JKR/SPJ/2012 Section 6: Road Furniture, Sub-Section 6.3: Road Markings (2012) [1], hereinafter referred to as SPJ. Malaysia is the first country in Southeast Asia that uses the AWT road markings, its inception in October 2010. Befitting the tag 'all-weather', the road markings could be clearly visible in all weather conditions, especially at night and when it rains. Fish (1996) defines all-weather road markings as markings that are visible at night under dry conditions and also under rainy conditions up to 0.25 inches per hour of rainfall [2].
However, there are dissatisfactions that the AWT road markings do not last long. This would cause discontent among the road authorities as the price of AWT road markings is three times more expensive than the ordinary thermoplastic road lines. So what could have gone wrong?

2. Road markings
AWT (or high performance thermoplastic) road markings comprise of high performance thermoplastic powder, inter-mix reflective beads and drop-on beads. In general, the performance of the AWT road markings depends on three parameters, namely materials, applicator machines and workers.

2.1. Materials
2.1.1. Material specifications. As specified in clause 6.3.2 of the SPJ, thermoplastic materials (ie. the white or yellow powder) shall comply with BS EN 1871 (2000) [3]. High performance thermoplastic powder which complies with BS EN 1871 and certified by recognised agencies should always be used; materials of inferior quality will not hold the drop-on beads firmly even though the beads are properly embedded during application. If the white thermoplastic powder change its colour to greyish or yellowish if overheated, that is a clear indication of inferior quality thermoplastic material that should be immediately rejected from sites. Substantial different in cost (~ 35%) between the superior (RM2,700/ton) and inferior (RM2,000/ton) product may encourage the contractor to use the cheaper product if enforcement is lacking. Materials without certification should not be accepted.

2.1.2. Reflective beads. The thermoplastic material should contain inter-mix reflective beads, and these beads should comply with BS EN 1424 (1998) [4]. In addition, during application on to the road surface, drop-on reflective beads are dropped (usually by gravity) shortly after the heated thermoplastic material is spread, and these beads should comply with BS EN 1423 (1998) [5]. Both BS EN 1424 and 1423 refer to glass beads, with a minimum value of refractive index (ability to refract light in water) of 1.5.

Other types of reflective material such as micro-crystalline ceramic beads* have higher refractive index of 2.4. The ability of the ceramic beads to reflect light towards the source of the light (ie. retro-reflection. In the context of road lines, it is the ability of the beads to reflect light towards vehicles’ driver) is claimed to be similar to diamonds. For normal glass beads, the refractive index is relative low (usually about 1.5), but there are high performance glass beads with refractive index of 1.9. Beads of inferior quality will not be able to reflect light towards the vehicles’ drivers, or reflect the light towards many other directions (diffuse reflection). During the day and when it does not rain, normal glass beads are sufficient, but at night or when it gets dark, especially when it rains, the superiority of the ceramic beads will be more pronounced. Micro-crystalline ceramic beads are claimed to be seven times brighter than glass beads.
The quantity of inter-mix beads is not specified in the SPJ. It is recommended that it should be not less than 10% by weight of the thermoplastic powder with at least 3% ceramic beads. For drop-on beads, the quantity is specified to be not less than 400 g/m². However, the proportion of each type of beads is not specified. It is recommended that the drop-on beads should contain at least 30% of micro-crystalline ceramic beads (refractive index > 2.4) with the remaining composition consists of 70% high performance glass beads (refractive index > 1.9).

2.1.3 Performance specifications. SPJ clause 6.3.2 stipulates that the performance of the thermoplastic road line material shall comply with BS EN 1436 (2007) [6]. Among other things, the BS EN 1436 specifies; (1) Luminance factor $\beta$ in dry condition not less than 0.60; (2) Luminance coefficient under diffuse illumination $Q_d$ not less than 160 mcd/m²/lux. (Note: If the luminance factor $\beta$ can be achieved, $Q_d$ does not need to be evaluated, and vice versa); (3) Coefficient of retro-reflected luminance $R_L$ in dry condition (ASTM-E1710) [7] not less than 300 mcd/m²/lux; (4) Coefficient of retro-reflected luminance $R_L$ in wet condition (ASTM, E2177-11) [8] not less than 75 mcd/m²/lux. (Note: $Q_d$ measures the brightness of the road markings in day light illumination and street light, while $R_L$ measures retro-reflection when lighted by vehicles' headlamp.)

The SPJ specifies that the $R_L$ shall be not less than 300 mcd/m²/lux in dry condition, and not less than 75 mcd/m²/lux in wet condition, within 7 days after the road markings are laid. However, after acquiring more knowledge on good and bad practices in laying road lines, the Superintendent Officer is encouraged to request the contractor to carry out the testing on the 6th or 7th day to allow any loose drop-on beads, if there is any, to detach prior to testing. Consequently, the requirement on the $R_L$ will
be reviewed and changed accordingly. It has been suggested that the requirement for the test to be carried out ‘within 7 days’ be changed to ‘within 10 – 20 days’ while the minimum value of $R_L$ remain unchanged.

In the opinion of the European Union Road Federation, ERF (2013) [9], a good road markings are those with performance level under dry conditions not less than 150 mcd/m$^2$/lux, whereas for wet conditions, the minimum performance level should be 35 mcd/m$^2$/lux. Apart from this, Fish (1996) [2] stated that most research has come to a conclusion that a minimum acceptable level of retro-reflectivity is around 100 to 120 mcd/m$^2$/lux.

Asdrubali et al (2013) observed that while the only performance parameter considered was $R_L$, at urban level the reflection in daylight condition $Q_d$ is equally (or more) important [10].

### 2.2. Applicator machines

#### 2.2.1. Drop facility for beads

If a mixture of glass beads and micro-crystalline ceramic beads is used as a drop-on reflective element, the applicator machine should be equipped with a double-drop facility with two units of dispenser. The larger ceramic beads (typically 1.1 - 1.3 mm) should be dropped first, followed by the smaller glass beads (usually 0.7 - 0.8 mm). If the smaller glass beads fall first, it would impede the larger ceramic beads from filling up the space in between the smaller beads, and this can lead to the larger beads get easily detached from the road markings by the passing traffic. Similarly, the larger ceramic beads would be loosely embedded into the road markings if both types of bead drop simultaneously from a single-drop facility with one unit of dispenser.
2.2.2. Height of spreader shoe. The height of the spreader shoe above the road surface should not be too high. It is recommended that the height should be 40 – 50 mm. If it is higher, there is a possibility that up to 10% of the drop-on beads will be blown away before they reach the road markings by the wind or passing traffics. It should not be too close either because the drop-on beads will not satisfactorily embed into the road markings. The target is to get the beads embedded into the road markings layer by about 50 – 60%.

A study elsewhere has shown that high retro-reflectivity could be achieved if the degree of sinking of glass beads is between 55 and 60% of their diameter. A sinking degree less than 50% weakens their resistance to tyres, while a sinking degree higher than 60% limits the retro-reflection properties [9].

![Figure 11. Embedment of drop-on beads](image)

2.2.3. Speed of application. The applicator machine should not be pushed too fast as some of the relatively light glass beads or ceramic beads will be blown away by the wind.

2.3 Workers

2.3.1. Laying thickness. The optimum thickness of the overlaid thermoplastic powder is typically 2.0 - 2.5 mm. If thinner, the drop-on beads would not stick firmly to the road markings. If thicker, most of the drop-on beads would sink into the road markings.

![Figure 12. The optimum thickness is 2.0 – 2.5 mm.](image)
2.3.2. Road surface condition. Prior to the application of the road markings, the surface of the road should be clean and dry. Surface which is dirty, sandy and wet would cause the road markings to easily peel off. After rain, it is advisable to wait for at least 12 hours for the moisture on the road surface to dry. The formation of small holes (pinholes) on the road markings indicates that the road surface has not adequately dried when the road markings are installed. It is also recommended that road markings are installed not less than 72 hours after paving works to let the bitumen sufficiently harden.

2.3.3. Overheating. If the thermoplastic material is inadvertently overheated above the recommended mixing temperature, the viscosity during application, and thus the embedment of the drop-on beads, will be affected even though the material is allowed to cool down.

2.3.4. Mixing and laying temperatures. The mixing temperature of the thermoplastic material should be as recommended by the supplier. Usually the temperature is 200 - 220 °C. However, if the road markings are installed in the evening when the temperature is a bit cooler, or in cooler highlands, the mixing temperature should be increased up to 230 - 240 °C. Laying temperature (the temperature of the thermoplastic material as it flows out from the spreader shoe) should be similar to the mixing temperature. If applied at cooler temperatures, the drop-on beads would not stick firmly while if the temperature is higher, the drop-on beads would sink. While the R_L could be achieved when the test is carried out within seven days, the loosely attached drop-on beads would eventually detach from the road markings by passing traffics. In contrast, the R_L could not be achieved when a lot of drop-on beads sink into the road markings if the laying temperature is too hot. The applicator team should be equipped with hand-held contactless thermometers to rapidly check the temperatures.

Figure 13. The mixing temperature should be as recommended by the material’s supplier.

Cold applied plastic road markings can be laid at ambient temperatures. The material is in liquid state at relatively low temperature and consists of a variety of additives. It is fast-curing and thus can be laid more speedily - will harden and can be opened to traffic after 20 minutes. The cold applied plastic road marking is said to be extremely durable - it lasts longer than the thermoplastic.

3. Degradation of road markings
The rate of degradation of the road markings varies with traffic volume. However, how fast the retro-reflectivity decreases over a time period is still unknown. Consequently, the SPJ presently only specify the initial minimum coefficient of retro-reflected luminance R_L of 300 and 75 mcd/m²/lux, in dry and wet conditions respectively, which are required to be achieved within seven days after laying the road markings.
3.1. Test sites
Subsequently, an actual field installation has been carried out to study the rate of degradation of the road markings with the AADT (Annual Average Daily Traffic) as the main parameter. Two states have been selected for this study namely Selangor and Melaka.

3.1.1. Selangor. Four sites have been selected with different composition of AADT with a general assumption of the classification as low, medium and high AADT. The classification considers the low, medium and high AADT volume road to experience about 1000, 4000 and 8000 AADT per lane respectively. The Level of Service (LOS), which refers to the extent of traffic congestion, is considered for the next governing parameter. The selected roads experience LOS A (no congestion – free flow with low traffic volumes and high speeds) for two sites, LOS B (no congestion – reasonably free flow, but speed depends on traffic flow) and LOS E (severe congestion – very unstable flow, possible short stoppages) for one site each.

3.1.2. Melaka. Three sites have been selected based on the composition of traffic ie. high, medium and low AADT. High AADT location is on Site1 (LOS F) Route FT 5 Masjid Tanah to Sg. Udang, medium AADT location on Site 2 (LOS E) Route FT 5Ramuang China Besar- Masjid Tanah and low AADT location on Site 3 (LOS C) Jalan Lubok Cina-Masjid Tanah. At each site, there are seven types of road marking test bars that have been installed which comprise of four different types of high performance thermoplastic and three varieties of cold applied plastic.

At each of the selected sites, the road marking test bars have been installed transversely on the pavement surface comprising of three bars of size 300 mm across a single lane width to accelerate the degradation, and one bar installed longitudinally on the edge line as the control bar. Timm and Priest (2005) [11] has shown that the wheel hit count on the wheel track area is on an average of seven times more than the wheel hit count on the edge line. Based on this, it was assumed that \( R_L \) on the wheel paths degrades seven times faster than the edge line at the trial sites. For example, \( R_L \) on the wheel paths obtained on Day 30 is equivalent to \( R_L \) obtained on Day 210 on the edge line. Nevertheless, the degradation of \( R_L \) by accelerated months is presumptuous.

![Figure 14. Site 1, Route FT55, Ampang Pechah. Traffic volume 1,514 (757/lane), LOS A (Selangor).](image1)

![Figure 15. Site 2, Route B54, Kuala Kubu Bharu. Traffic volume 9,415 (4,708/lane), LOS A (Selangor).](image2)
Figure 16. Site 3, Route FT54, Assam Jawa. Traffic volume 21,278 (7,093/lane), LOS B (Selangor).

Figure 17. Site 4, Route FT5, Kuala Selangor. Traffic volume 35,845 (8,871/lane), LOS E (Selangor).

Figure 18. Site 1, Route FT5, Masjid Tanah. Traffic volume 21,167 (10,584/lane), LOS F (Melaka).

Figure 19. Site 2, Route FT5, Ramuan China Besar. Traffic volume 16,916 (8,458/lane), LOS E (Melaka).

Figure 20. Site 3, Route FT5, Jalan Lubok Cina. Traffic volume 11,202 (5,601/lane), LOS C (Melaka).
Figure 21. Three-year accelerated test results obtained from wheel paths (trial sites in Selangor).
3.3. Discussion
In general, it was observed that the transverse bars degrade drastically from Day 1 to Day 56 (equivalent month is 0.25 to 12.1). The degradation tends to stabilize after that with about 10-15% percent variation, and diminishing consistently up to Day 125 (equivalent month is 29.6). Although $R_L$ dry dwindle, it still exceeds 150 mcd/m²/lux after equivalent three years at trial sites with LOS A, meeting the minimum acceptable $R_L$ as suggested by European Union Road Federation (ERF, 2013). The $R_L$ dry and wet values show a consistent correlation, with steep degradation during early life and stabilize at later stage. The reduction of $R_L$ is significantly affected by LOS. The trial site with LOS E shows the most drastic degradation during the first month. This could be possibly due to traffic behaviour with extreme change of vehicle speed over a short length. However, the coefficient of $R_L$
exceeds 100 mcd/m²/lux after equivalent three years, meeting the minimum acceptable $R_L$ [2]. It is worth to note that the fluctuation of $R_L$ observed throughout the monitoring period could be attributed to dirt and debris.

Figure 21 shows that high performance reflective beads maintain a consistent trend of deterioration over time in dry and wet conditions, without the wet performance being compromised. LOS (Level of Service) highly affects the rate of deterioration and retained $R_L$ values (referring to the high-AADT Sites 3 and 4). The high-AADT Site 4 with LOS E records passing values of $R_L$ dry 142 mcd/m²/lux and $R_L$ wet 35 mcd/m²/lux after 30 months. Other trial sites with lower AADT and LOS record retro-reflectivity exceeding the recommended minimum retained $R_L$ values in dry and wet conditions after 36 months.

Figure 22 shows that $R_L$ dry and wet at Site 3 (low AADT LOS C) are 127.0 mcd/m²/lux and 54.3 mcd/m²/lux respectively. These values were achieved after a period of four years. While for Site 1 with the highest AADT (LOS F), $R_L$ dry and wet are 101.0 mcd/m²/lux and 30.6 mcd/m²/lux respectively after four years.

The best performance of cold applied plastic achieved $R_L$ dry and wet of 180.9 mcd/m²/lux and 84.8 mcd/m²/lux respectively after four years. The best performance of high performance thermoplastic (at trial sites in Melaka) achieved $R_L$ dry and wet of 281.8 mcd/m²/lux and 64.2 mcd/m²/lux respectively after four years. This give an indication that the high performance thermoplastic is slightly better than the cold applied plastic. Nonetheless, it is worth to note that both types of road marking were able to last at least for four years as both $R_L$ dry and wet still exceeded 100 mcd/m²/lux and 35 mcd/m²/lux respectively after that period.

However, comparison of road marking having reflective beads with similar characteristics such as thermoplastic A and cold applied plastic Z indicates that the cold applied plastic records higher $R_L$ after four years. This shows that the cold applied plastic has a stronger bonding with the beads than the thermoplastic.

4. Conclusions
For countries like Malaysia, being located in the region with tropical climate and experiencing frequent heavy rainfall, it is imperative to have all-weather thermoplastic road markings for the safety and comfort of the road users. Some good practices which are based on past experience have been highlighted and these are recommended to be adhered to in order to consistently produce high quality road markings.

Based on trial sites in Selangor, the high performance thermoplastic records passing value of $R_L$ dry and wet after 30 months at the high-AADT site. Based on more recent trial sites in Melaka, both the high performance thermoplastic and cold applied plastic record passing values $R_L$ dry and wet after four years. However, the cold applied plastic provides higher $R_L$ which indicate that it could hold the reflective beads more firmly than the thermoplastic.

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