Advances in retroreflective technologies for road signage, vehicle visibility and pavement markings, delivering safer roads for all

King, A.
3M Traffic Safety Systems Division

Abstract:

This paper provides an overview of recent advancements in road signage, vehicle visibility and pavement marking technology developed by 3M and how they can be applied to improve safer navigation on the road, especially for large vehicles and compromised situations.

Keywords:
Retroreflectivity
Diamond Grade
All Weather Paint (AWP)
Stamark

Introduction:

3M is a global diversified technology company with operations in over 60 countries worldwide. 3M's products span numerous market areas from consumer and medical through to mining, industrial and safety products. 3M Traffic Safety Systems division is the world's leading manufacturer and supplier of retroreflective materials for road safety applications. The key focus of 3M Traffic Safety Systems is 'keeping people safer through better visibility,' primarily achieved through a commitment to ongoing research, development and advancements in retroreflective technologies.

Although most commonly used in signage, retroreflective materials are also widely used for vehicle safety markings, road marking and a variety of other safety applications. A number of fundamental advances with these materials have occurred in recent years and changes have also been made to standards globally to embrace these improved technologies. This paper aims to highlight such technological advancements and explore the importance of effective signage, vehicle visibility and line marking in improving safer navigation of the road, for all road users.

Body of Paper:

Historical perspective of retroreflective materials

Signage on our road network has long been a major contributor to the safety of motorists and is key to providing direction, warning and information when travelling on our roads. The history of signage on our roads is not clearly documented but the need for more road signage increased dramatically with the use of the motor vehicles from the early 1900's. With the massive road building programs that took place after WWII in the USA during the 1950's, there was a move to gain standardisation in road signage across all states to improve detection and recognition of street signage for motorists travelling across state borders. This standardisation has continued today with many countries moving to adopt international standards which standardise typical road sign characteristics including: shape, colour, font/legend type and retroreflective ability.

During the day, sunlight allows most signage materials to provide adequate sign visibility. However, with the absence of natural light at night, drivers rely entirely on a sign's visibility from alternate light sources, such as headlights. In the early 1900's an inventor identified that animals seen at night through headlights could be located by the reflected light from their eyes. He pursued this factor to look to see if he could reproduce this light reflection with a man-made material and was able to replicate this effect using a large glass bead with a reflective coating on part of the surface. This first use of these large glass beads was effective in providing some level of visibility for road signage and was mainly used to outline the font/legend of the sign only. The process of returning light back to its source is known as retroreflection.

The development of retroreflective sheeting materials dates back to the 1930's and since this time has seen some major developments in improving the efficiency of the sheeting with advance in technologies at a microscopic level. The original products produced used the glass bead technology that is still in use today. In the 1980's, technology evolved to the use of microprismatic materials. Microprismatic reflective materials consist of microscopic air-filled, resin prisms that have been impressed into the internal structure of the sheeting with precision tooling. These prisms then reflect incident light by a process known as "total internal reflection", where the light enters the prism and reflects off multiple faces of the prism and is then returned to the light source. By modifying the microprismatic geometry during manufacture of the sheeting, the divergence cone of light can be altered such that the light can be preferentially distributed to areas in the cone where it is most likely to be useful to the driver or application. Herein lays the great advantage of prismatic retroreflective sheeting's over traditional glass bead based materials.

By comparison the original glass bead technologies were producing around 8% returned light and doubled to around 16% in the 1970's with the introduction of 'high intensity' glass bead products. The move to the microprismatic construction saw the doubling again of the returned light in the 1990,s up to 32% and this has increased further in recent years with the introduction of 3M's DG^3 Full Cubed technology in 2005.

<u>How retroreflection works</u>

As outlined previously, retroreflection is the returning of light from a given surface directly back to its light source. In our case, from the headlight of a motor vehicle illuminating a traffic sign and returning that light back to the driver.

To fully appreciate how retroreflective materials can help make our road safer at night it is helpful to understand the major factors that influence the overall luminance of a sign and the properties of the returned light to the source. The angles that influence the return of light are known as the entrance angle and the observation angle and the returned light is referred to as the cone of reflected light or divergence cone.

The entrance angle is the angle formed between a light beam striking a surface at some point and a line perpendicular to the surface at the same point. The entrance angle continuously changes as a car moves toward a sign as the angle increases. All retroreflective sheeting materials have lower retroreflectivity at wider entrance angles with some performing better than others. For road engineers, this is an area where they can have particular influence in improving sign visibility and safety through the placement of the signage and the sign sheeting they select to be used.

Observation angle is the angle between the line formed by the source of the light beam striking the surface and the retroreflected beam returned to the driver's eyes. In other words, the size of the angle is determined by the vertical distance between the headlight of the vehicle and the driver's eye level. Therefore, the observation angle is significantly larger for truck drivers than motorists in cars, because of their larger vertical displacement from the headlights. This causes a significant reduction in the amount of returned light received by the truck driver, compared to the light received by the driver of the car. Less reflected light means less driver ability to detect, recognise and read a sign.

When light is reflected off a sign, it does so in the shape of a cone. This 'cone of reflection' spreads wider over a longer distance from the sign. The retroreflected light is brightest near the centre of the cone and becomes less bright as it expands outward.

The measurement of retroreflective materials is done through various measures of luminance, based on differing entrance and observation angles. The efficiency of retro reflective materials varies with differing observation and entrance angles, and these readings are presented in photometric tables.

The role of retroreflection in improving road safety

In understanding the technology behind retroreflectivity we can start to build a link with how this affects real drivers in everyday (or night) driving situations. We understand the need for clear, conspicuous and legible signage to improve driver safety and this is especially important when driving at night as conditions are generally acknowledged as more difficult and harder to navigate.

If we consider the factor of the entrance angle, we can easily identify that not all signs are placed in the same position in respect to the vehicle and this placement will affect their visibility. Consider a major highway where you have signage on the left and right hand side of the road as well as on overhead bridges and gantries. The light emitted from a car headlight at low beam will give almost 100% luminance to the sign on the left hand side of the road as car headlights are directed more to the left hand side in order to cover the verge and not shine into the eyes of oncoming traffic. The sign on the right hand side of the road however will only get 26% of that light. A direct overhead gantry sign receives only 18% and a gantry sign overhead and to the right it is typically as low as 16%. This clearly illustrates that sign placement has a large effect on sign visibility and brightness that could effect the accurate reading of those signs. On rural roads the need to be able to clearly read signs and delineate the road is especially important. Therefore, sign placement and the type retroreflective sheeting used can have a profound effect on the road's level of safety.

As discussed above with observation angles, we highlighted that there is an effect on sign visibility dependant on the type of vehicle being driven. All vehicles will have differing observation angles as the vertical height difference between the headlight and the driver are not all the same. This is especially obvious when you consider the difference between a car and a truck where a car at 200 metres may have a 0.2^0 observation angles and a truck 0.5^0. This differential has a large impact on the light returned from a sign and in some cases a sign that may be visible from a car is not visible from a truck. This is because the cone of reflection is not wide enough to be able to return light to the wider angle of the truck driver. When you consider that road freight has been growing steadily at around 5.8% for the past 25 years and 4WD's make up 20% of new vehicle sales, there is an increasing need for signs that perform to the wider observation angles.

There is a great deal of awareness of the aging population that we have in this country and the impact on services such as health. The aging population are also road users and their needs in navigating the roads need to be understood in order to improve safety. A study in the USA [1] has found that older drivers have trouble navigating roads, which were not designed with them in mind. For many of these motorists signs are hard to read, lanes are too narrow and left hand turns (right hand turns in Australia) are very difficult. Intersections are a particular problem and according to the study, 50% of all fatal accidents involving older drivers are at intersections, compared to 25% for other drivers.

It is understood that as we age our need for light to be able to read doubles around every 13 years after the age of 20. Drivers over the age of 60 require approximately 8 times more light and their reaction times increases, needing around 40% more time to react than younger drivers.

Many studies have been done on the performance of sign sheeting and the legibility and response times at various distances. However, there has been little study on the effect of luminance on sign legibility performance. A recent study from the University of Iowa: *Effect of Luminance on Information Acquisition Time and accuracy from traffic Signs,* [2] investigated the effect of (legend) luminance and letter size on the transfer accuracy from simulated traffic signs. The study stated that: "…traffic sign and retroreflective sign sheeting performance at night have been historically identified with the threshold (farthest) distance for legibility, and in many cases from stationary vehicles with no restrictions on viewing time. Since traffic signs are not always read at threshold distances or threshold luminance's and since the time to read traffic signs are usually limited in the real world, a proper assessment of sign legibility performance requires determining information acquisition times above threshold conditions."

The study states also states that: "…the sole function of a traffic sign is to convey its information to the driver. Conveying information is achieved visually, which is not an instantaneous task. While driving, traffic sign reading is not a primary task, but it requires the driver to divert visual attention and have an eye fixation on the sign. Sign reading has to be effortless and quick, allowing the driver to redirect visual attention back to the roadway and attend to the driving task." Therefore how quickly a driver can read a sign with high accuracy is just as important as whether the sign is legible and where reading takes place.

The findings of the study suggest that increasing the sign luminance significantly reduced the time to acquire information. It found that: "…larger and brighter signs are more efficient in transferring their message to the driver by reducing information acquisition time, or alternatively, by increasing transfer accuracy. In return, reduced sign viewing durations and increased accuracy is likely to improve roadway safety."

Previous studies have already highlighted the safety impacts of drivers who are not paying enough attention while driving. Activities such as using a mobile phone or other in-car technologies while driving have alerted road safety experts of the effect of eyes-off-the-road time. *Dewar et al: Human Factors in Traffic safety* [3] stated: "…for improved safety, the primary characteristic of interest is eyes-off-the road time. This time is the sum of all of the time associated with glances not directed toward the road, plus transition time from off the road to the road. Except for scanning mirrors and instrumentation, driver safety is compromised if one is not looking at the road." Furthermore, there is potentially a need for road safety signage and markings to be detected faster and earlier.

3M's latest technology – Diamond Grade Cubed DG^3

To further improve on the efficiency of microprismatic sheeting, 3M needed to completely rework the structure of its existing microprisms in its sheeting. This has been achieved by designing a prism geometry called Micro Full Cube, or simply Full Cube Technology. In effect the full cube reflective sheeting design takes the reflective area of the microprismatic (cube corner) design and discards the ineffective corners. These reflective centres are replicated side by side to create a 100% retroreflective surface. When viewed in this fashion it appears a trivial development but in reality it is far from that. With the full cube prismatic design, the actual efficiency of the material is 58% once physical losses have been accounted for. That means 58% of the light which strikes the sign face is retroreflected to the driver in the cone of retroreflection.

As would be argued by many road users, the brightness of many signs do not need to be increased to improve their legibility. With the Full Cubed sheeting the increased efficiency is engineered to create a broader cone of reflection, thus using the additional light produced to reflect to broader range of observation and entrance angles. By carefully controlling the divergence, the light can be distributed without becoming blinding to any driver. In other words, retroreflectivity at narrow observation angles can be kept relatively equal to that of incumbent high performance sheeting, while retroreflectivity at wider observation angles has been significantly increased.

The big advantages in this Full Cube technology is that it provides greater luminance to large vehicles such as trucks that have a large observation angles. It also provides all vehicles greater light reflectivity from disadvantaged sign positions such as signage on the right hand side of the road, overhead gantry positions and winding roads where vehicles headlights do not focus as much light on the sign. There is also an advantage in the brightness to cater for older drivers and the current move toward the new VOA headlights in new cars which accurately limits the beam angle of headlights.

By providing more light to the driver of all vehicle types and improving the sign legibility for disadvantaged signs, 3M's DG^3 sheeting is seen as a breakthrough in improving the ability of drivers to read road signage and providing better road safety outcomes.

The role of fluorescent materials in improving road safety

The use of fluorescent materials is now well established and the advantages understood in improving the visibility of objects and people to increase safety. It is seen in use everyday with workers clothing on construction sites, road works, emergency services, warehouses etc.

Fluorescent materials are manufactured using pigments and dyes that are able to absorb a portion of the sun's (invisible) UV radiation and convert this radiation to visible light which is then emitted. This process is behind the exceptional visual impact that fluorescent colours possess during daylight hours. Put simply, there is more light being emitted from the surface of a fluorescent coloured material during the day than there is from a non-fluorescent coloured material. These materials are particularly visible during the hours of dawn, dusk, overcast periods and areas of reduced ambient sunlight such as in shaded areas. During these conditions and times non-fluorescent colours appear dull and inconspicuous.

It has been studied that fluorescent retroreflective materials are detected with higher frequency and are recognised with greater accuracy at further distances than the corresponding standard highway colours [4]. This increase in the ability to recognise signage earlier gives the ability for a driver to react faster thus increasing the safety of all road users

Fluorescent materials are increasingly being used on Australian roads in signage applications.
Fluorescent yellow-green is gaining an association with pedestrian activity in the drivers mind. Similarly, fluorescent orange is most widely used for certain Construction Work Zone signs but also in school zones in some Australian states. Fluorescent yellow is increasingly being used in warning signs to improve daytime visibility and is more visible than the current standard yellow used.

The use of these fluorescent materials in road signage is another way to improve sign visibility during daylight hours and thus improve road safety. The current Australian standard for Pedestrian Signage AS1742-10 has recently been reviewed and puts forward that all pedestrian related signage in Australia should now be Fluorescent yellow-green. The RTA in NSW has recently announced that all of its school zone signs that are currently standard yellow will be upgraded to fluorescent yellow green in the future to improve safety.

Current Australian Standards

The Australian and New Zealand Standard for retroreflective material for road traffic are covered under the standard AS1906 series. Specific road signage standards are covered under the AS1742 series (1 – 15)

This 1906 standard was last reviewed in 2007 with the introduction of a new class of material know as Class 1W. Class 1W was introduced as a standard above the Class 1 to allow for the specifation of a product that provided greater photometric values at wider observation and entrance angles. Most traffic signage in Australia is now based on Class 1 or Class 1W retroreflective sheeting.

With the introduction of these new technologies, the photometric values for the sheeting have significantly improved, and at this point there has been no change to the Australian standard to reflect a new class of material that provides superior performance. The American Society for Testing and Materials (ATSM) in the USA has recently reviewed its classes of materials for retroreflective sheeting's and has introduced a Type XI into its classifications that covers the new higher specifications of full cubed technology.

The role of retroreflective materials in improving vehicle safety

The adoption of retroreflective materials for vehicles has long been a part of the Australian market and the rear marking of heavy vehicles and trailers is covered under the Australian standard AS4001 – (2003) series. The side marking for heavy vehicles is not covered under a standard but there is a voluntary code of practice that was produced in 2003 by the Australian Trucking Association and is based on the European Regulations UN/ECE 104.

Although these standards and code do recommend the use of reflective materials they are based on older technology and lower performing sheeting than are currently available.

The use of high performance retroreflective markings of vehicles is increasing in some areas and is becoming a more widely used method to improve safety in markets such as emergency vehicles, where vehicle conspicuity is very important. Although flashing lights are very important for emergency vehicles to increase visibility, retroreflective markings substantially add to this visibility from all angles and do so at relatively low cost. Other areas where this safety improvement is becoming more widely used is in the mining industry to improve the day and night time visibility of both large and small vehicles. Retroreflective markings are also used in the railway industry which impact road safety in areas such as level crossings to improve night time visibility of train movements.

To further improve vehicle visibility, especially in the areas of heavy vehicles and road working vehicles, it should be considered to adopt new vehicle marking guidelines and increase standards to improve safety. For heavy vehicles this may be based on the UN/ECE 104 and look to include upgrading of all vehicles to have high performance retroreflective markings on their sides. For Road Work vehicles which includes Construction Work Zone vehicles, as well as vehicles that may be doing work on or near a road eg: Electricity, water, road services etc, the use of the retroreflective materials would improve their overall visibility and increase their workplace safety.

As outlined above, the use of products such as 3M's DG3 not only provides brighter vehicle markings, but it also provides wider angle viewing so the vehicle and objects can be identified sooner from wider angles and at great distances. This greater viewing distance and angularity can improve the safety of those vehicles on the road as many of the vehicles are never viewed directly side on. The use of fluorescent materials will also improved conspicuity during daylight and low light times and is an added safety factor.

Wet Reflective Pavement Markings

It has long been understood the increased danger in driving in wet conditions with accidents rates increasing up to three times of that in the dry. [5] Driving at night in the wet only increases that risk. The challenges of driving in these conditions include rain hitting the windshield, movement and condition of wipers, steamed windshield, glare from oncoming cars, headlight misalignment, road spray and the difficulty of light transmission through the rain.

A large part of the difficulty in driving in the wet stems from the inability to find the delineation of the road between lanes and the verge. Basically the road line markings become difficult or impossible to see and vehicles can find themselves in the wrong lanes or on the wrong side of the road.

Like older retroreflective road signage, line marking uses glass bead technology to be able to retroreflect the lines back to the driver to give them visibility during the night. The technology is proven and is used in all types of line marking materials such as paints, thermoplastics, tapes and other materials. However, because of the physical properties of the glass beads when water is applied to the surface, the retroreflection is refracted and the visibility of the line is reduced.

This issue has long been considered and many attempts have been made to overcome the problem. The technical reason for this problems is that the refractive index of the glass bead is 1.5 – 1.9 and to be able to reflect with water over a surface a refractive index of 2.4 is required. 2.4 is about the refractive index of a diamond.

In recent years 3M has released a microcrystalline ceramic element that is able to attain the 2.4 refractive index and is now been utilised in many road line marking systems. This new 'wet reflective element' is able to provide wet reflective properties to road line marking and is seen as a breakthrough in line marking technology. The product was introduced into the Australia market in 2008.

The 'All Weather System' requires both the dry reflectivity glass beads and also the wet reflective elements to be able to work in all conditions. Because it is impossible to have an element that provides both wet and dry night time visibility both of the products are applied onto the paint or thermoplastic marking. In essence, the glass bead works whilst the weather is dry and the wet elements 'switch on' when the road surface is covered with water and the dry elements 'switch off'.

This new system should improve road safety by increasing the visibility of line marking in wet conditions. There are several trials being run in various states throughout Australia and new upgraded specifications have been included in some states in the USA. There are also several large trials and research being undertaken in the US. At present most of the road authority standards do not include any wet reflectivity measurements as the technology is new, but work is being done to better understand the technology and its benefits.

As well as the stand alone elements 3M has a range of line marking tapes for the road industry with wet and dry reflective attributes. These tapes are hard wearing and also offer the benefits of being visible in all types of weather conditions. They are easy to apply and take away some of the need for road services crews to close roads whilst doing small line marking jobs. They are adhered with a pressure sensitive adhesive and can be laid quickly on the surface with pressure applied to gain the adhesion required.

Another area where these tapes are offering safety benefits over existing systems is for temporary markings in construction work zones. Because they are easy to apply and remove it is easy to put in place diversions quickly and safely and they provide better line delineation under the more dangerous work zone conditions in both wet and dry conditions. There is also a black out tape available that will cover the existing line marking to eliminate the confusion of which line the driver is suppose to be following.

3M is currently doing several studies on the benefits of all of our pavements markings products in some projects through the FHWA in the USA. Some of these studies are focused in work zone areas that are considered more dangerous driving conditions and a greater need for better line delineation.

Conclusion

The recent advances in retroreflective technologies for road signage, vehicle and line markings should be leveraged to improve road safety for all Australian road users. With

Black Spot funding increased to record levels in the most recent federal budget there is a unique opportunity to consider the benefits and low cost of improving road signage and line marking as part of any Black Spot plan. In a study by the FHWA (USA) the organisation identified that the improvement of traffic signage had a benefit / cost ratio of 22.4:1.

To highlight the need to improve and upgrade our roadways a recent study from the USA titled '*On a crash course: The Dangers and health cost of deficient highways'* [6] identified that more than half of the US fatalities are related to deficient highways. This is a substantially more lethal factor than drunk driving, speeding or non use of seat belts. The research identifies ways that transportation officials can improve road conditions to save lives and reduce injuries. For example, immediate solutions for problem spots include: replacing non-forgiving poles with breakaway poles, **using brighter and more durable pavement markings**, adding rumble strips to shoulders, mounting more guardrails and safety barriers and installing **better signs with easier-to-read legends'.**

For road signage to be as effective as possible, it is important that all road users and the road environment are considered during the material design and specification stages. It has been established that in the critical sign reading distances, the observation and entrance angles and the retroreflective brightness are important factors that effect sign visibility. With this in mind, signage materials should be specified to deliver the bulk of their retroreflectivity within a range to benefit all road users.

In many cases there is a need to improve the asset management of signage and conduct audits at night to properly measure their retro-reflective values and night time performance. When it comes to road signage, the fact is 'what you see during the day is not always what you see at night' and performance can differ substantially. Road authorities and traffic engineers have very little control over many factors that impact sign luminance, however they can control the specifications of the retroreflective sheeting that they use and also the effective positioning of the sign.

It is also beneficial to consider the advantages in the use of fluorescent materials in signage to improve its impact for all road users. Motorists are constantly bombarded with all types of signage - traffic and commercial, especially in urban areas. The use of fluorescence assists in detecting signage earlier and at greater distances which allows more reaction time for the driver.

The adoption of the high performance retroreflective sheeting for usage in vehicle marking is another safety improvement for many road users. The inclusion of fluorescent materials can also improve daytime visibility and a review of some standards needs to be undertaken to take into consideration the latest technology.

With the introduction of new wet reflective line marking technologies there is now an opportunity to improve the road safety problem of line delineation in the wet. This product can be easily applied through existing line marking equipment with some modifications. It is relatively low cost method to improve road conditions in known high accident areas when it is wet and at night.

Governments at both state and federal levels need to more proactively evaluate new technologies to advance road safety. The Federal Highways Administration (FHWA) in the USA actively works with, and fund, departments of transport (DOT's) and private enterprise for research and evaluation of new road safety materials. This initiative should be considered through the new National Road Safety Council of Australia with joint activities and testing carried out in Australian conditions. There also needs to be a move away from road safety materials such as lines and signs being included in the road maintenance budget where there are limited funds and consider them as core road safety products. This may require further long term investment and acceptance of increased costs to improve the performance of the materials used.

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