



Report on Testing
and Approval of
Roadmarking
Materials

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INTRODUCTION

The aim of this report is to review the testing requirements for the approval of roadmarking materials for use in New Zealand. The review is limited to the materials used for linear longitudinal markings although the principles could also be applied to other forms of roadmarking materials.

Before considering what tests are appropriate for approving a roadmarking material it is important to establish clearly what the purpose of the approval process is. The New Zealand Transport Agency's (NZTA) specifications for roadmarking paint (New Zealand Transport Agency 2009) include:

- On-road performance tests
- Laboratory performance tests
- Application properties
- Quality control tests

From these specifications we can infer what the agency is trying to achieve. The on-road performance tests are an attempt to measure the durability of the material in-service. The laboratory tests measure various properties relevant to the in-situ performance of newly applied delineation. The application properties requirements relate to characteristics of the paint that affect whether it can be applied satisfactorily, while the quality control tests are intended to ensure that, within specified tolerances, each batch of paint is identical to the paint that was tested and thus that its performance will be acceptable. Without appropriate quality control tests, the other tests are meaningless. In addition to these tests there are some basic requirements relating to paint composition. These relate primarily to environmental impacts (e.g. paints shall be lead-free).

The specifications for long-life roadmarking materials – thermoplastic and cold applied plastic – are specified in a separate document (Transit New Zealand 2003). These specifications differ from those for paint in some respects most notably the lack of quality control requirements. It appears to be assumed that these materials are covered by patents and licensing agreements and that this will ensure consistency. The field testing requirements are similar to those for paints, while the composition and properties requirements are analogous to the application properties and laboratory performance requirements for paints.

It is worth noting that these specifications set minimum performance levels for the material to be approved for use. They do not explicitly rank the materials or assess cost-effectiveness.

Roadmarking contracts in New Zealand fall into one of two categories of specifications: methods-based and performance-based. With the methods-based approach, the section of road to be marked, the marking layout, the type of product to be used and the thickness at which it is to be applied are all specified. Some basic performance criteria are included in the contract but the requirements are primarily prescriptive. More recently there has been a move towards performance-based contracts. With these, the contractor is required to provide roadmarkings on a section of road to specified performance level for a specified period. The contractor has much more flexibility to choose the roadmarking material used and the application thickness. With methods-based contracting, the road controlling authority needs to be confident that the material used will perform satisfactorily and thus it is important to have a list of approved materials that are known to have satisfactory performance. With performance-based contracts, in theory there should be no need to approve materials based on performance criteria. Clearly the environmentally-based conditions still need to be imposed but performance requirements are incorporated in the contract. If the contractor chooses to use a material that performs poorly they will pay the price. However, in practice there are benefits from having approved materials. From the contractors' point-of-view having a list of approved products is useful because they know these products have been tested in New Zealand conditions and have passed, while from the road controlling authority's perspective there is a reduction in the risk of poor performance requiring intervention.

In this review we begin by considering different types of testing that can be undertaken and the benefits and limitations of these. We then review the road marking materials approval processes in different jurisdictions and compare these with New Zealand. Finally, we review the existing testing regime and approval process and assess whether changes should be made to improve its performance in terms of reliability, timeliness and cost-effectiveness.

TESTING PROCEDURES FOR ROAD MARKING MATERIALS

There are numerous international standards relating to roadmarking materials. (Stoffers 2000) lists 14 European standards specifically on road marking materials. ASTM International (ASTM 2011) lists 19 current standards on their web-site relating to pavement marking paints and coatings. In Australia, the Australian Paint Approval Scheme has a specification for road marking paints (APAS 2007) which in turn references the relevant Australian standards. The standard AS4049 has five parts covering the different types of pavement marking materials and performance assessment of them. In addition there are a number of other standards that are relevant such as those for glass beads, for colour and for testing retroreflectivity.

These testing procedures vary from laboratory tests for specific properties through to on-road tests under real traffic. Generally there is a trade-off between control of the test conditions and applicability to the real world use of the product. Having tight control of the test conditions should ensure that the results are accurate, reliable and repeatable but they may not directly reflect the in-service use of the product. On-road testing, on the other hand, is more closely aligned to the end-use of the product but it is more difficult to control the test conditions and hence the reliability and repeatability of the results may be compromised.

It is important to recognise that roadmarking is a “system” (Potter Industries Pty Ltd 2007) consisting of a number of components and processes. Apart from the paint or other coating material, the system includes the road surface type and condition as well as any preparation work done to it prior to applying the marking, the glass beads, adhesion coatings, accelerants, binders, fillers, anti-skid materials and the application system and the environmental conditions at the time of application. The performance of the system depends on all of these elements not just the paint or coating material alone.

Like many jurisdictions the NZTA has a list of approved products that may be used in New Zealand. To be approved the product has to meet the specifications for the type of product as outlined in the previous section. The specifications include the testing requirements to show compliance. The requirements for paint (New Zealand Transport Agency 2009) have been updated much more recently than the requirements for long-life materials (Transit New Zealand 2003) and there is now some inconsistency between the two specifications.

The composition requirements in the paint specification include revised limits for the heavy metal content of the glass beads and require all paints to be lead-free. The specifications for long-life materials have not been updated to include these changes and thus does not include heavy metal limits on the glass beads and still includes provision for lead chromate to be used in the yellow product. The other composition requirements for long-life products (thermoplastic and cold applied plastic) identify the components of the products and, in the case of thermoplastic, specify proportions and particle size distributions. There is no similar specification for the proportions of the components in the cold applied plastic. Clearly the composition requirements for paint exist to manage the environmental impacts of the materials as they wear. The composition requirements (binder content and bead content) for thermoplastics appear to be related to durability and on-going performance but there is also a requirement for a field test to check durability.

For each of the composition requirements the testing procedures are defined in the specification documents. Although some of these procedures refer to various standards for the most part they are standalone descriptions. Because there are a number of these and they are quite detailed we have not gone through and compared them with the equivalent tests defined in the various standards. It is likely that they are very similar but we cannot say that they are identical. All of these tests are laboratory-based and thus should be highly repeatable and have good precision.

The two sets of specifications also prescribe a series of laboratory tests to measure performance and application properties. For paints the properties tested for are:

- Colour

- Specular Gloss
- Dry Time "No Pickup"
- Dry Through Time (Early Washout)
- Condition in the Container
 - As Received
 - After Storage
- Residue on Sieve
- Consistency
 - As Received
 - After Storage

The tests for these properties are all laboratory tests and are all referred back to procedures defined in the relevant Australian and New Zealand standards.

For long-life materials a comparable set of property tests is defined for thermoplastic materials. The properties tested for are:

- Colour
- Luminance
- Heat Stability
- Softening Point
- Flow Resistance

These are also all laboratory tests but most of them are defined in the specification itself rather than by reference to standards. Again we have not analysed in detail what the differences are between these test procedures and those specified in various international standards. The requirements do differ from those given in AS 4049.2:2005 which is the Australian standard for this material. It is also notable that, although the NZTA specification covers cold applied plastic, no equivalent set of property tests is defined for this material.

The final set of tests required in New Zealand is the on-road performance tests. These are intended to measure the durability of the materials in real world conditions. Both sets of specifications (New Zealand Transport Agency 2009; Transit New Zealand 2003) require on-road performance tests but again there are significant differences between the two which result from the specification for paints having been updated more recently. The two major changes are a change in the way that retro-reflectivity is measured and the introduction of the option to use an alternative testing regime using in-situ lines rather than transverse lines in a dedicated test zone. In both cases the testing involves measuring various line properties:

- Degree of Wear
- Luminance
- Retroreflectivity
- Colour
- Skid-Resistance

The field testing programme for paints provides for three levels of durability, A, B or C corresponding to 1Million(M), 1.5M or 2M vehicle passes respectively. For the test using transverse lines, it is specified that for each product four lines are marked – two beaded and two unbeaded. Measurements are taken immediately after the lines have been placed and then at two, approximately equal, intermediate intervals before the final measurement after 1M vehicle passes have been applied. For an extended wear classification (B or C) further measurements are taken after 1.5m and 2M vehicle passes. This transverse line test specifies that the pavement surface should be chipseal, preferably grade 3, in good condition. An alternative in-situ testing regime is also specified. The test period for this test depends on the average traffic expected at test site. However, it is very non-linear. For example, at the lowest level of trafficking (AADT=600) the lines will experience 219,000 vehicle passes during the test period for A classification while at the highest level of trafficking (AADT = 15000) the lines will experience 2,737,500 vehicle passes. These two sets of test conditions are deemed to be equivalent. As with the transverse line tests a minimum of four set of measurements are required – one immediately after the lines are placed, two intermediate sets and one on completion of the trial. For lower traffic volumes the road surface is expected to be chipseal but for higher traffic volumes open-graded asphalt is also acceptable. The test site is 2km long and within

that site three 200m long monitoring sites must be identified. Each monitoring site is divided into four and within these 50m sections a 5m long measurement section is defined. Thus each test site has twelve 5m long measurement sections. Thus in-situ requires significantly more measurements, than transverse line testing, which are then averaged to indicate performance.

For longlife materials, the specification is older and only the transverse line test is provided for. For these materials the minimum durability limit is 3M vehicle passes. The specification provides for the test to be undertaken on either chipseal or asphalt. However, if the test is done on asphalt the material can be approved for smooth surfaces only while if it is done on chipseal it can be approved for all surfaces.

Field tests are not the only approach used for durability testing. In Germany they have developed an accelerated testing facility as shown in Figure 1 (Keppler 2008). The facility has up to eight tyres so that the test samples can be subjected to 8 wheel passes per revolution and up to 20 different material samples can be tested simultaneously. The maximum rotation speed is approximately 100 rpm so that, theoretically, 1M vehicle passes can be simulated in a little over 40hrs. In practice, of course, time is needed to set up the test and to take measurements at various intervals but nevertheless a test can be completed in a matter of weeks. Furthermore the facility is air-conditioned with both temperature and humidity control so that the effects environmental factors can also be assessed. A similar facility has also been established in Spain.

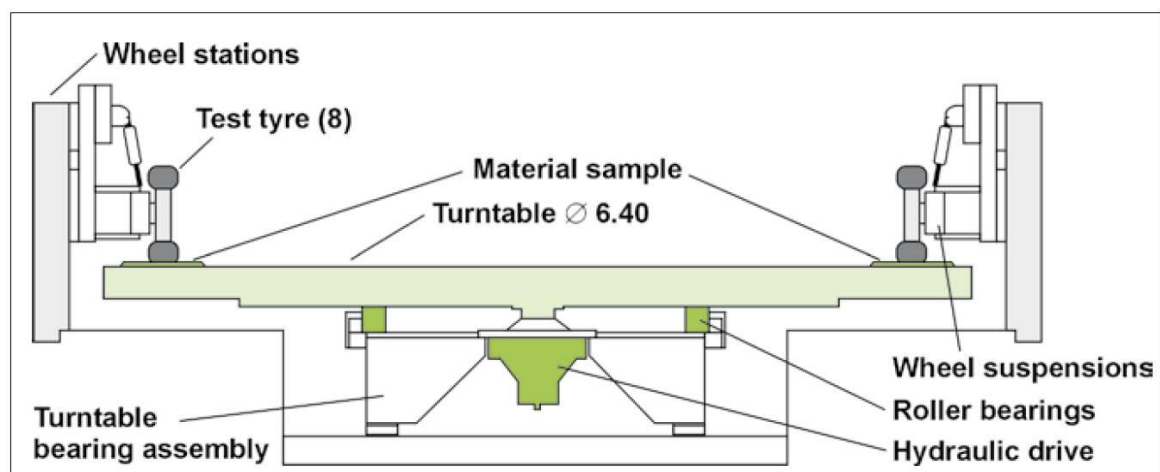


Figure 1. BAST accelerated testing facility.

A European standard, EN 13 197 has been developed for undertaking roadmarking material tests using a wear simulator (Keppler 2008). This system has been used in Germany for approving roadmarking materials since 1989.

On a smaller scale there is also the Taber Abraser, shown in Figure 2, which is used in some jurisdictions for testing the resistance to abrasion wear for line marking materials. This is a laboratory device where a test specimen of the material is mounted on a rotating turntable while two loaded wheels on an axis that is offset from the turntable axis are used to cause abrasion to the material surface. There are various options for the abrading wheels with different levels of aggressiveness and the load on them is controlled. The standard loads are 0.25kg, 0.5kg or 1kg but other values are possible. To show the scale of Figure 2, the test specimen is a little over 100mm in diameter



Figure 2. Taber abraser.

INTERNATIONAL PRACTICE

Australia

In Australia each state has its own requirements for roadmarking materials and these vary considerably. However there is a national scheme for approving paints known as the Australian Paint Approval Scheme (APAS) which has a specification for roadmarking paints (APAS 2007). There are also a series of national standards, the AS 4049.n series for roadmarking materials. The states differ in which of these standards they require.

New South Wales has an extensive set of specifications relating to pavement marking materials (RTA NSW 2007; RTA NSW 2009a; RTA NSW 2009b; RTA NSW 2009c; RTA NSW 2010a; RTA NSW 2010b; RTA NSW 2011). For the most part these specifications refer to the appropriate Australian standards. For materials to be certified for use in New South Wales, they need to undergo a series of laboratory tests similar to those specified in New Zealand and field tests similar to the transverse line tests required in New Zealand. These tests are specified in detail in the AS4049 standards. It is notable that the specifications for longlife products include a test for abrasion resistance using the Taber abraser as well as the field tests. Also the test conditions for the field tests are not identical to those specified in New Zealand. The RTA specification (RTA NSW 2009a) says that the paint must be tested on asphalt but the Australian standard it refers to (AS4049.3) says that paints can be tested on either chipseal or dense graded asphalt, although the asphalt test requires twice as many wheel passes. Thermoplastic can be tested on either chipseal or dense asphalt but the asphalt requires five times as many vehicle passes while for cold applied plastic the RTA specification includes only asphalt as the test surface. Although the paint specification (RTA NSW 2009a) does not exclude solvent-based paint, the quality standard for pavement marking (RTA NSW 2011) explicitly requires written approval for solvent-based paints to be used. Thus the expectation is that paints will be waterborne.

The Queensland situation is much simpler. There is a standard specification (Queensland Government 2007) which allows either waterborne paint or thermoplastic materials to be used. It appears that solvent-borne paints are no longer used in Queensland. Although the specification does not include cold applied plastic marking it does appear that these are used. Paint is required to be "... conforming to the requirements of AS 4049.3 and having approval under the Australian Paint Approval Scheme – Specification 0041/5", and "Thermoplastic materials shall comply with the requirements of AS 4049.2 and have approval under the Australian Paint Approval Scheme – Specification 0041/4". In both case the APAS specifications require that field testing is undertaken and the field tests specified in AS 4049.2 and AS 4049.3 are transverse tests.

In South Australia there is a specification for the supply of pavement marking materials (Government of South Australia 2011e) which requires that only approved materials are used. This specification has an appendix listing all currently approved materials. For each type of material it refers to a procedure for having the material certified and approved. The three types of pavement marking materials currently allowed are waterborne paints, thermoplastics and multi-component high performance materials and the relevant certification procedures are (Government of South Australia 2011a; Government of South Australia 2011b; Government of South Australia 2011c; Government of South Australia 2011d). Note that solvent-borne paints are not included. The certification procedures for these materials refer to the relevant Australian standards and include the usual set of laboratory tests. However, they all have a mandatory requirement for "in-service testing by a recognised test authority or documented history of performance from a state road authority". Data from field tests using transverse lines may also be considered but the in-service testing is mandatory. The test periods for the in-service tests are relatively long. For paints the minimum is 15 months when the traffic volume is high and longer when it is low. For the other materials, a relatively high traffic volume is required and the minimum duration is two years.

The ACT has a set of specifications for infrastructure works which include a section on pavement marking (Australian Capital Territory 2002). The paint requirements in this section specify waterborne paints complying with AS 4049.3. The longlife materials allowed are thermoplastic or cold applied plastic where the thermoplastic is required to comply with AS4049.2 and the cold applied plastic is required to comply

with the New South Wales specification 3360 (RTA NSW 2009c). Thus all three products require field testing using transverse lines.

Tasmania similarly has a set of standard specifications for pavement marking (The State of Tasmania 2010). This also allows for the use of waterborne paint and thermoplastic and refers to the Australian standards and the APAS approved list:

“Road marking materials shall conform to the following Australian Standard, Australian Paint Approval Scheme Specifications and shall be on the current APAS List of Approved Products:

- (a) AS 4049.2 Thermoplastic material approval system
- (b) APAS 0041/5, Road Marking Paint, water borne.”

Cold applied plastics are listed separately with a requirement that “The contractor shall provide evidence that ... have demonstrated satisfactory field performance for a period of at least three (3) years.” Solvent-borne paints are not used any more.

Overall Australia has a set of standards for these materials and a national scheme, APAS, which tests the materials and produces lists of approved materials. Individual states do set the own specifications but smaller states appear to simply refer back to the APAS approved list. The most populous state, New South Wales does have an extensive set of its own specifications and tests but most of these refer back to the Australian standards.

North America

Like Australia, the states in the USA and the provinces in Canada set their own specifications for pavement marking materials. In Canada we have even found specifications set by a city (City of Edmonton 2004). The USA has a national testing programme called the National Transportation Product Evaluation Program (NTPEP) (AASHTO 2005). The field tests undertaken under NTPEP use test decks in different areas in the USA to reflect the diversity of environmental conditions. All of the data from these tests can be accessed on-line at www.ntpep.org. These are all transverse lines tests and are done in accordance with the ASTM D713 standard.

In California there is an overall set of standard specifications for all road works (Caltrans 2010c) which includes a section on pavement marking. This section, in turn, references a series of specifications for the different materials that can be used (Caltrans 2006a; Caltrans 2006b; Caltrans 2006c; Caltrans 2009a; Caltrans 2009b; Caltrans 2009c; Caltrans 2010b). These specifications are quite detailed and include a range of laboratory tests, operational properties and quality control requirements but they do not require field trials except in the case of solvent-based paint. However, the laboratory tests do include durability tests such as accelerated weathering and abrasion/scrub resistance. The quality control requirements are quite rigorous. The California Department of Transport operates its own testing laboratory and requires samples of every batch or lot of product to be submitted for testing before shipment. The manufacturer’s own test reports for that batch have to be submitted with the sample.

Although the Californian specifications include solvent-based paints, waterborne paints and thermoplastics, the guidelines for selecting materials for pavement marking (Caltrans 2006a) recommends thermoplastic as the default material for all new pavements. Paints are listed as being suitable for temporary markings and epoxy systems are suggested as being suitable for snowplowed areas particularly on concrete roads. Note that there was no specification for epoxy material but Caltrans maintains a list of approved products (Caltrans 2010a). These products still require samples to be submitted for quality control testing with every batch used.

Oregon similarly has a set of specifications for pavement marking materials (ODOT 2009; ODOT 2010a; ODOT 2010b) but they also have a qualified products list which can be viewed on the internet (<http://www.oregon.gov/ODOT/HWY/CONSTRUCTION/QPL/Docs/QPL.pdf>). The Oregon specifications include field testing in the state-run testing program with transverse lines on both asphalt and concrete pavements. Conditional approval can be obtained without the field testing results but full approval requires these results. As well as testing for minimum acceptable performance (i.e. out-performing the control paint), the tests on paints also calculate a service life index which reflects the durability of the paint which can be used to calculate the cost-effectiveness of the product. This service life index approach is not

used for high-performance or durable products which are required to be manufacturer-guaranteed (ODOT 2008). The warranty period for high performance products is one year while the period for durable products is three years for thermoplastics and four years for all other products. These products must be installed by manufacturer-certified installers. Interestingly, however, the standard specification (ODOT 2009) states that “*ODOT uses lead-free, waterborne traffic paint for all long-line projects that don’t require a durable product*”.

The Texas Department of Transport (TxDOT) publishes a pavement marking handbook (TxDOT 2004). This refers to the material specifications for waterborne paint and thermoplastic (TxDOT 2006; TxDOT 2009). It notes that “*TxDOT has not allowed solvent-based paint for many years, relying exclusively on water-based formulations. In addition, most state DOTs have disallowed solvent-based paints.*” This is a response to environmental concerns related to the volatile organic compounds (VOCs) used in solvent-based paints. Texas does allow other materials such as epoxy and cold applied plastic to be used but there are no standard specifications published for these materials. The specifications for waterborne paints and thermoplastics are quite specific in terms of the composition on the materials and include both weathering and abrasion/scrub tests but have no requirements for field tests. TxDOT retains the right to sample and test materials. These tests are done TxDOT’s expense unless the product fails in which case the manufacturer is required to pay. TxDOT maintains lists of approved manufacturers and products.

In Canada there are even specifications at the city level (City of Edmonton 2004). This includes specifications for thermoplastic, cold applied plastic and paints. These specifications are based on ASTM standards. Interestingly for paint they require field testing using transverse lines while for thermoplastics and cold applied plastic they do not. For these latter products they do specify a Taber test for abrasion resistance.

Europe

As noted previously Europe has 14 European standards relating to pavement marking (Stoffers 2000). These are listed below:

EN 1436	Roadmarking materials – Performance for roadusers
EN 1423	Roadmarking materials – Drop on materials – Glassbeads, antiskid aggregates and mixtures of the two.
EN 1424	Roadmarking materials – Premix glassbeads
EN 1463-1	Roadmarking materials – Retroreflecting road studs – Part 1: Initial performance requirements
EN 1463-2	Roadmarking materials – Retroreflecting road studs – Part 2: Road tests performance specifications
prEN 1871	Roadmarking materials – Physical properties
prEN 12802	Roadmarking materials – Laboratory methods and identification
EN 1790	Roadmarking materials – Preformed roadmarkings
EN 1824	Roadmarking materials – Road trials
EN 13197	Roadmarking materials – Wear simulators
prEN 13212	Roadmarking materials – Requirements for the factory production control
prENV 13459-1	Roadmarking materials – Quality control. Part 1 – Sampling and testing from storage
prENV 13459-2	Roadmarking materials – Quality control. Part 2 – Guidelines for preparing quality plans for the application of roadmarking products
prENV 13459-3	Roadmarking materials – Quality control. Part 3 – Performance in use.

One of the aims of the European Union has been to set standards that apply across the whole of Europe so that products approved in one member state can be freely used in any other member state. Having country specific requirements is generally viewed as a barrier to free trade. However, this is problematic because the different states do have different needs. As Stoffers points out, the Scandinavian countries require resistance to low temperatures and studded tyres as an important performance characteristic while the southern European countries do not. This issue has been addressed by establishing different classes for each of the requirements. The main standard describing these requirements is EN 1436 and this has been required to have been adopted as a national standard across all member states since 1998.

However, although EN 1436 describes the performance requirements of roadmarking systems it does not specify an approval process for materials. Methods for determining these material performance characteristics are described in the various other standards. In the UK materials used in road marking are required to be assessed for performance (Department for Transport et al. 2004) using laboratory tests as detailed in EN1871 and road trials as described in EN1824. The UK manual does not include provisions for the road trials to be substituted with wear simulator trials.

In Germany the BASt accelerated wear facility was developed to overcome some of the difficulties associated with field testing. It has been used for product approval testing since 1989 testing approximately 150 different marking systems per year (Keppler 2008). Materials are approved for use in Germany without road tests on the basis of laboratory tests and accelerated testing results.

In the Netherlands, road marking materials used on public roads are required to be certified. The product certification procedures (Kiwa Nederland B.V. 2009) refer to the European standards, EN1436, EN1871, EN 1790 and EN1824. It does not refer to wear simulator tests and so in the Netherlands pavement marking materials are required to undergo road tests to be approved for use. As well as product certification procedures there is also mandatory certification of contractors. This appears to be primarily establishing that the contractor has an effective quality system in place that is being used properly.

South Africa

In South Africa road marking materials are required to be certified by the South African Bureau of Standards (SABS) (Labuschagne 2011). There are South African standards for solvent-borne and waterborne paints as well as for glass beads (Standards South Africa 1997a; Standards South Africa 1997b; Standards South Africa 2006a; Standards South Africa 2006b), but there are no South African standards for thermoplastics or cold applied plastic. However there is some thermoplastic use in South Africa. One South African road marking company lists the specification on its web-site (Lanino Traffic Markings 2011). Road marking is required to be done in compliance with the "South African Road Traffic Signs Manual" (SARTSM). For thermoplastics the SARTSM specifies meeting the British standard, BS 3262. But BS3 262 has now been superseded by EN1436.

(Grosskopf 2001) also presents an overview of South African road marking practice. He also notes that road markings are required to comply with SARTSM. However, he argues that SARTSM does not specify minimum performance requirements although it does make suggestions. Grosskopf argues that the specifications in the contracts fail to adequately specify performance or quality control requirements. Note that this paper was written in 2001. The specifications on the Lanino web-site (Lanino Traffic Markings 2011) do indicate initial values and minimum values for retroreflectivity with performance-based contracts.

Although we have not found a definitive source detailing all the requirements it appears that materials are required to comply with standards and to be certified as complying by SABS. This certification process does not appear to require field testing.

REVIEW OF TESTING AND APPROVAL PROCESSES IN NEW ZEALAND

We now consider whether the processes used for testing and approving road marking materials in New Zealand are as effective as they could be. To begin with it is important to establish what we are trying to achieve from these processes.

The high level goal of the NZTA is to implement the most cost-effective safety counter-measures available. It is very well-established that road-marking is a cost-effective safety counter-measure (Perkins 2008). In fact, Perkins also quotes another study showing that road markings are very cost-effective in reducing congestion and improving travel times. Having established that road-marking is a cost-effective intervention, we can modify the goal to one of implementing the most cost-effective road-marking systems. Thus as we review the testing and approval processes for road marking materials we need to consider whether the processes further the goal or not and whether or not some alternative process might not be more effective.

A fundamental problem we have is that all the testing requirements set benchmark criteria that a material must achieve in order to qualify for use on NZ roads. These are minimum requirements and the process does not differentiate between products that only just qualify and products that qualify with a margin to spare. If the superior product is more expensive, it is less likely to be used for methods-based contracts even though it may last longer, perform better and be more cost-effective. This argument does not apply to performance-based contracts where the contractors will be aiming for the most cost-effective solution – assuming that the audit process is working effectively. The NZTA can address this issue by monitoring both the performance-based contracts and the methods-based contract to establish what the differences are in choice of material and application thickness and what the differences are in terms of outcomes such as intervals between re-marking allowing for traffic volume and environmental conditions. If it is found that performance-based contractors are achieving superior performance then the NZTA should investigate how the methods-based contracts can be restructured to encourage contractors to adopt the same practices and materials as performance-based contractors.

As noted in the introduction a range of tests are required for a road-marking material to be approved for use in New Zealand. The simplest requirements are the environmental ones which include lead-free paints and limitations on the heavy metal content of the glass beads. There is an anomaly in the current specifications in that M20 has not been updated for some time and thus still allows lead chromate in yellow paint. Although, in practice, it is unlikely that lead is still being used in these products this oversight should be remedied as soon as possible. Internationally many jurisdictions have eliminated solvent-borne paints from their list of allowed materials and only allow waterborne paint. This is in response to concerns about the adverse effects of the volatile organic compounds (VOCs) present in solvents. It also appears that waterborne paints if applied correctly tend to have superior performance to solvent-borne paints but are more expensive. As discussed in the previous paragraph this may mean that they are more-cost-effective. It would be useful to resolve this because over time there will be increasing pressure to reduce or eliminate the use of solvent-borne paint.

The other tests required for product approval address four aspects of the materials:

- Application – can the material be applied satisfactorily to a road surface using standard road-marking equipment?
- Performance – does the material have the right properties in terms of colour, luminance etc.?
- Durability – will the material last for a reasonable period in-service?
- Quality assurance – is each batch of the material in good condition and of the same composition as the sample that was tested for approval?

The testing procedures used to evaluate these aspects range from laboratory-based to field trials. In the laboratory the test conditions can be controlled to a great degree and generally the measurements can be undertaken with a high degree of precision. Thus it is possible to achieve good repeatability. However, the test procedure will often not reflect the real world circumstances very accurately. Field trials, on the other hand, are much more realistic but it is often difficult or impossible to control the test conditions and it is

often difficult to take measurements with the same degree of precision as is possible in a laboratory. Consequently there is often a greater degree of variability in the results and the same level of repeatability is not achieved. Note that tests are not necessarily purely laboratory or purely field test. For example, for some tests samples are prepared by placing thin metal plates on the road in the path of a road marker so that the paint is applied in exactly the same way as it is in service but these samples are then taken back to the laboratory for testing.

Currently the application properties, the performance characteristics and the quality assurance are all tested using primarily laboratory-based tests. In general these tests are similar to those required in other jurisdictions although the pass/fail criteria are not necessarily identical.

In New Zealand the quality control tests are undertaken by the paint manufacturer and reported to the NZTA. This differs somewhat from some US states where the manufacturer also has to supply samples of each batch to the state testing laboratory and thus the state can test themselves and cross-check the manufacturer's reported results. Most other jurisdictions do not take this approach. Nevertheless, a satisfactory quality assurance system is fundamental to any scheme where materials are tested and approved for use. Without quality assurance and quality control tests there is no way of ensuring that the material currently being used is the same as the material that was tested and approved. There does not seem to be any good arguments for the NZTA to sample every batch of material but they should reserve the right to require samples to be provided and from time-to-time should arrange independent testing to confirm the manufacturer's results. This is particularly important when there is other evidence to suggest that a product is not performing satisfactorily.

The laboratory tests for application properties and performance characteristics required by the New Zealand M7 specification are similar to those required in other jurisdictions. However, they are not identical. Both the test conditions and the pass/fail criteria can differ. This is the case even for the Australian standards (AS 4049 series) which is slightly surprising because the earlier versions of the Australian standards were joint Australian and New Zealand standards. Where the test method is the same but the pass/failure criteria differ, laboratory test results from other jurisdictions could be recognised but where the test conditions are different the results are not directly comparable. Thus it appears that paints which have been tested and approved overseas would need to be retested in New Zealand to check for compliance with our requirements. While it would be impossible to make our requirements compatible with every set of international standards it does seem sensible to harmonise our requirements with those in Australia. Alternatively we could exempt from laboratory testing materials that have already been tested and certified as complying with internationally recognised standards. This would require some detailed checking of the international standards to ensure that their requirements are comparable with those required in New Zealand. The limited analysis undertaken for this review suggests that they are comparable.

One other notable difference between the testing requirements in New Zealand and those internationally is the requirements imposed on the testing agencies. In Australia, the specifications generally require that the testing is done by organisations that are accredited to the National Association of Testing Authorities (NATA). New Zealand has a similar government body, International Accreditation New Zealand (IANZ), for accrediting testing organisations and ensuring competence. The M7 and M20 specifications in New Zealand do not require IANZ accreditation. M7 makes reference to the testing agency being "competent" while M20 makes no reference to this at all. Given that NZTA has limited capacity to assess the competence of testing agencies it would seem sensible to require this competence to be verified through requiring accreditation by IANZ, NATA or other internationally recognised bodies.

The final aspect of the materials that is tested before approval is durability. Currently in New Zealand this is done through field tests using transverse lines or in-situ tests monitoring normal markings at specific sites. Internationally, field tests using transverse lines are the most widely-used method although the European standard, EN1824, also provide for field test with longitudinal broken lines across the width of the lane forming a matrix of test markings. In some jurisdictions laboratory tests relating to durability such as weathering and abrasion tests are used sometimes in addition to and sometimes instead of field tests. In Germany and Spain accelerated wear simulators are used instead of field tests.

Field tests are time-consuming and expensive to undertake. Consequently, in New Zealand, they are undertaken relatively infrequently and thus a requirement for field testing seriously hampers the introduction of new (or reformulated) road marking materials. To overcome this bottleneck, there is provision in the M7 specification for in-situ testing. Internationally allowing in-situ testing for product approval is rare but it is notable that in South Australia it is mandatory.

Although transverse line field tests are widely-used and accepted internationally they have been problematic in New Zealand and it is worth considering whether they are cost-effective and whether or not there are better alternatives. The basic premise of the field test is that the road markings are being tested in more realistic conditions than in the laboratory. The downside of this is that test conditions are less well-controlled and so we expect more variability and uncertainty in the results. Thus there is a trade-off between realism and reliability.

The issue of realism is an interesting one. A number of jurisdictions, including New Zealand, require the field testing to be undertaken locally so that they reflect local conditions. In New Zealand this particularly relates to performance on chipseal pavements. However, many other aspects of the test are different from the in-service situation. For the field test the lines are applied using a walk-behind marking machine operating at, perhaps, 4km/h. In-service lines are applied using truck-mounted marking machines operating at 15-20km/h. Clearly to achieve a specified paint thickness different nozzles and/or pressures are required for different speeds. Similarly the glass beads applied at fixed rate per sq. m of line and so must be applied more rapidly when the marking machine is moving more quickly. As noted by (Potter Industries Pty Ltd 2007) road-marking is a system comprised of a number of components including the paint or long life material, the glass beads, the road surface and the method of application. Thus the difference in application method between the field tests and the in-service situation does affect the relevance of any results. A second important issue is the direction of the lines. One of the key measures of performance is retroreflectivity which is a function of how well the material retains the glass beads. In the field tests, the retroreflectivity is measured in the direction of the line while the traffic, which causes the loss of glass beads is perpendicular to the line. For in-service lines the critical retroreflectivity is in the direction of the traffic flow and vehicles will contact the line in the same direction. (Potter Industries Pty Ltd 2007) points out that on textured surfaces like chipseal the retroreflectivity is often directional with the glass beads favouring the "approach" side of the stone. This would suggest that the direction of the vehicle crossings will also affect the rate at which the retroreflectivity declines. Thus there are significant differences between the field trial test conditions and the in-service situation.

A bigger problem in New Zealand has been the variability and reliability of the results. In 1999-2000, (Dravitzki et al. 2001) undertook a series of field trials to investigate the effect of various parameters on the consistency of the results. The parameters considered were:

- Variations between morning and afternoon placement of the lines
- Variations between placement on consecutive days
- Variations between placement in different seasons
- Variations between placement at different locations
- Variations between different applications methods and equipment.

Three paints of different types were tested at three different test sites. Lines were laid at the test sites in December, March, July and October reflecting the four seasons. Measurements were taken at 330,000, 660,000 and 1 million vehicle passes and then at 500,000 increments. One of the sites showed degradation after the first set of measurements and this was attributed to contamination from roadworks about 2km away. However, the second set of lines at this site also failed prematurely even though the road appeared clean and the third set failed even though the site was waterblasted first. Thus this site was eliminated from the analysis. The two measures of performance reported were wear and retroreflectivity. The variability in performance measured in these trials was very large. For example, the retroreflectivity of waterborne acrylic had an average value of 165 mcd/m²/Lux with a standard deviation of 41 mcd/m²/Lux. This means that the 95% confidence range is 84-247 mcd/m²/Lux which is from well below the minimum acceptable level up to near new condition. Thus in an actual field trial where a product could be represented by only two test lines it is not unlikely that a false pass or fail will be recorded. Dravitzki et al claim that in spite of the substantial range of performance, the field trial is sufficiently consistent to identify differences in performance. Without the raw data it is impossible to test this assertion but it does not appear to be correct in all circumstances. Furthermore the field test requirements specify absolute

performance not relative performance and in this case a large number of samples would be necessary to be confident of the results. The major sources of variation in the trial were site location and the season the trial started with some day-to-day effect for some paint types. Dravitzki et al suggest addressing these issues by pre-trialling proposed test sites with control materials of known performance, applying control paints on each day of testing and possibly limiting the seasons in which trials can start.

In-situ testing is less controlled than field testing because it is impossible to determine whether vehicles have travelled on the lines and at which locations. Thus although it is straightforward to estimate the number of vehicles that have travelled over the test site it is difficult to determine how many have crossed the lines and even more difficult to ensure that the measurements are taken at the locations that the wheel passed over. Nevertheless the measurement protocol specifies that the number measurements taken is much larger than during a field test and this will help to reduce the uncertainty of the estimate of average performance. Note that effectively in-situ testing is just a formalisation of in-service monitoring and because of this should take as long as the material lasts. The M20 specification for long life materials does not include the option to do in-situ tests. While this omission is probably because the M20 specification has not been updated since before in-situ testing was approved, in-situ tests on long life materials could potentially take three years or more.

Our understanding is that a pre-trial of a potential field test site near Wellington has just been undertaken. One of the providers of a control product has used the same product from the same batch for an in-situ test on SH1 south of Christchurch. Thus we have results from both the trial field test and an in-situ using identical material. For the field test six lines were placed and five readings were taken of each line while for the in-situ test measurements were taken at 12 locations and 16 readings were taken at each location. The field test measurements were taken after 400,000 vehicle passes while the in-situ measurements were after 12 weeks and approximately 300,000 vehicle passes. The M7 specification for in-situ tests indicate that for the level of traffic at the site the test should run for 9 months and thus the measurements are at one third of that period. The 95th percentile mean retroreflectivity at the field test site was 157 ± 27 mcd/m²/Lux while the reading from the in-situ site was 110 ± 5 mcd/m²/Lux. The corresponding results for luminance were 159 ± 15 and 126 ± 2 . There is a significant difference in the performance of the material between two sites for which there are many possible reasons. However, it is notable that the confidence interval for the measurements is much smaller for the in-situ tests. Furthermore, the field trial used six lines where only two are needed. With only two lines to measure the variability in the field trial results would be expected to be higher. On the other hand, the failure level for retroreflectivity is 100 mcd/m²/Lux and thus it appears very likely that the material at the in-situ site will fail before the 9 months has elapsed although it may well pass at the field trial site. This material was being used as a control for the field trial and is an approved material currently in use in New Zealand. Hence it is a concern that it will fail the in-situ test.

In Germany and Spain wear simulator tests are used instead of field trials. A schematic of the German facility is shown in Figure 1. BAST accelerated testing facility. Figure 1. Using a wear simulator has a number of significant advantages. Test environmental conditions can be controlled, the simulated vehicle passes can be applied over a much shorter timeframe, and importantly the trials can be undertaken without disrupting traffic and without putting the testing personnel at risk. This last point is seen as very important in Germany. To undertake trials, particularly of long life materials, within a realistic timeframe requires that the test site is a heavily trafficked road and so the disruption is not insignificant and the traffic safety management requirements are high. The test panels on which the materials are applied are designed to have a composition and surface comparable with dense asphalt. Thus the results would not be representative of road marking performance on chipseal surfaces. However, it would not appear to be difficult to apply chipseal to a suitable backing material and create test panels that are representative of chipseal.

Some jurisdictions do not require field testing at all. They simply include some durability related tests with the required laboratory tests. It is not clear whether the outcomes from this approach are any worse than those for jurisdictions requiring field trials. The European standard for road tests, EN 1824, suggests using control products thus implicitly recognising the variability associated with these tests. In the UK, TRL undertook tests to see whether field trials could be substituted with laboratory tests (Nicholls 1995). Although they found that the laboratory tests could differentiate between materials they could not

replicate the field trial. This would seem to be primarily a calibration issue but we have not found any follow up research to address this.

CONCLUSIONS

This review has considered the processes used for testing and approving road marking materials in New Zealand. Currently materials are required to undergo a series of laboratory tests and field trials or in-situ tests to verify that they perform adequately. Qualifying materials are placed on approved list. This approach is quite widely used internationally although there are differences in the details. New Zealand and South Australia are the only jurisdictions we have found that use in-situ testing.

There are two approaches used for contracting road marking in New Zealand; methods-based and performance-based. With methods-based contracts the road controlling authorities need to have some way of ensuring that the materials used will perform satisfactorily and the approval materials list is one way of achieving this. With performance-based contracts the contractor is responsible for ensuring that the road markings perform and thus, in theory, there is no need for NZTA to specify approved materials except in respect to environmental factors such as lead-free paints and limits on heavy metal content in glass beads etc. Nevertheless for the contractor there is some value in having an approved products list because it provides him with an independent assessment of the materials' performance and for the road controlling authority the risk of poor performance is reduced.

NZTA currently has two specifications for these materials, M7 covering paints and M20 covering long life materials. The M7 specification is quite recent (2009) and includes the in-situ testing regime. However, some parts of the in-situ testing procedures appear to have been transferred directly from the equivalent sections in the field testing procedures and are incorrect. These should be modified. The M20 specification for long life materials is somewhat older (2003) and needs updating. Specifically it still allows lead chromate to be used in yellow product and it specifies that retroreflectivity should be measured with the MiroLux 12 photometer or equivalent. This has been superseded with 30m geometry device in M7 and the same should apply in M20. M20 also does not provide for in-situ testing. For long life materials in-situ testing could potentially take 3-4 years so it is not clear whether this is a viable option.

There are four aspects to the testing processes:

- Quality control
- Operational properties
- Performance characteristics
- Durability

Of these quality assurance and control is fundamental. There is no point in having the other requirements unless it can be guaranteed that the materials being supplied today are the same as those that were tested and approved. There should be some auditing of the manufacturers' quality control testing. In Australia this is done through APAS and a similar approach could be implemented here.

Operational properties and performance characteristics are determined through laboratory tests. These processes are similar to those required in other jurisdictions but not identical. It seems an unnecessary duplication of effort and cost to require materials that have already been tested overseas to be tested again in New Zealand. Therefore NZTA should establish whether or not compliance with the various sets of international standards is comparable with the New Zealand requirements and approve those that are. The main ones to be considered are the Australian standards, the European standards and the ASTM standards.

The specifications require that testing is done by "competent" personnel but does not define "competent". There is a New Zealand government agency, IANZ, which accredits competent testing providers. The specifications should require that all testing is undertaken by laboratories accredited by IANZ or other internationally recognised accreditation agencies.

A major motivation for this review was the field testing requirements for durability performance. These tests are expensive to undertake and have been undertaken very infrequently over the last 15 years. Furthermore, the results of these tests have shown great variability and thus are not very reliable particularly in the absolute sense. The provision to allow in-situ testing has come about because of the infrequency of field tests. Although field tests are widely used internationally, their poor performance in

New Zealand suggests they should be abandoned as a means of establishing durability. The current procedures for in-situ tests are effectively a protocol for monitoring in-service performance. Satisfactory in-service performance is a mandatory requirement for product approval in South Australia and this should be applied here. Ideally the approach should be extended so that the in-service performance of all materials used in road marking is monitored from time to time. New materials can be conditionally approved when they achieve satisfactory performance in the laboratory tests. The laboratory test requirements could be expanded to include some durability elements such as an abrasion test and a weathering test. Full approval would be given when the material has achieved satisfactory performance in-service based on the monitoring results. There could be some restrictions of the use of provisionally approved materials to encourage manufacturers to actively pursue full approval.

The current approval process sets minimum requirements for materials and does nothing to promote the use of better performing materials. A programme of in-service monitoring would identify better performing materials and thus the contracting process could be modified to encourage the most cost-effective options to be selected. This already occurs with performance-based contracts where the contractor gets the best results by choosing the most cost-effective material not the cheapest material. NZTA should learn from their experience and apply the same approach for methods-based contracts.

Accelerated wear testing on the European facilities could provide an alternate mechanism for going from conditional approval to full approval. However, before this can be done there would need to be some research to develop and test chipseal test panels and some trials to correlate the results with in-service performance measurements.

REFERENCES

- AASHTO. (2005). "2002 NTPEP - Pavement Marking Materials. Second Year Field Performance & Lab Test Results (2002 Mississippi Test Deck)." American Association of State Highway and Transportation Officials (AASHTO), Washington.
- APAS. (2007). "Pavement Marking Materials" *Specification 0041*.
- ASTM. (2011). "ASTM - Search Standards." ASTM. <http://www.astm.org/Standard/index.shtml>
- Australian Capital Territory. (2002). "Standard Specification for Urban Infrastructure Works, Section 11 Pavement Marking", Canberra.
- Caltrans. (2006a). "Guideline for Selecting Materials and SSPs for Traffic Striping and Pavement Marking", D. o. Transportation, Sacramento.
- Caltrans. (2006b). "Specification for Profilable Thermoplastic Traffic Striping Material, White and Lead-Free Yellow" *Specification PTH-02PROFILE*, D. o. Transportation, Sacramento.
- Caltrans. (2006c). "Specification PT-150VOC(A) for Paint, Acetone-Based/VOC-Compliant, Traffic Line, White, Yellow and Black" *Specification PT-150VOC(A)*, D. o. Transportation, Sacramento.
- Caltrans. (2009a). "Specification for Sprayable Thermoplastic Traffic Striping Material, White and Lead-Free Yellow" *Specification PTH-02SPRAY*, D. o. Transportation, Sacramento.
- Caltrans. (2009b). "Specification for Thermoplastic Traffic Striping Material, Alkyd Resin Binder, White and Lead-Free Yellow" *Specification PTH-02ALKYD*, D. o. Transportation, Sacramento.
- Caltrans. (2009c). "Specification for Thermoplastic Traffic Striping Material, Hydrocarbon Resin Binder, White and Lead-Free Yellow" *Specification PTH-02HYDRO*, D. o. Transportation, Sacramento.
- Caltrans. (2010a). "Qualified Products List of Two-Component Traffic Striping Paints and Large Gradation Retroreflective Glass Beads", Office of Materials Engineering and Testing Services, Sacramento.
- Caltrans. (2010b). "Specification PTWB-01R2 for Paint, Rapid Dry Waterborne Traffic Line, White, Yellow and Black" *Specification PTWB-01R2*, D. o. Transportation, Sacramento.
- Caltrans. (2010c). "Standard Specifications", D. o. Transportation, Sacramento.
- City of Edmonton. (2004). "Design and Construction Standards - Volume 8 - Pavement Marking", City of Edmonton, Edmonton.
- Department for Transport, Department for Regional Development (Northern Ireland), Scottish Executive, and Welsh Assembly Government. (2004). "Traffic Signs Manual - Chapter 5 Road Markings", Department for Transport, London.
- Dravitzki, V. K., Potter, S. M., and Walton, D. (2001). "Filed Trials of Roadmarking Materials." New Zealand Roadmarkers Federation Conference, NZRF, Rotorua.
- Government of South Australia. (2011a). "Certification – Multi-Component High Performance Pavement Marking Materials PC109 (Draft)", Department for Transport Energy and Infrastructure, Adelaide.
- Government of South Australia. (2011b). "Certification – Pre-form Thermoplastic Pavement Marking Materials (DRAFT) PC112", Department for Transport Energy and Infrastructure, Adelaide.
- Government of South Australia. (2011c). "Certification – Thermoplastic Pavement Marking Materials (DRAFT) PC113", Department for Transport Energy and Infrastructure, Adelaide.
- Government of South Australia. (2011d). "Certification – Waterborne Pavement Marking Paint PC108", Department for Transport Energy and Infrastructure, Adelaide.
- Government of South Australia. (2011e). "Specification: Part 245. Supply of Materials for Pavement Marking", Department for Transport Energy and Infrastructure, Adelaide.
- Grosskopf, S. E. (2001). "For Safety's Sake, Let's Do Road Marking Quality Control." 20th South African Transport Conference South Africa, 'Meeting the Transport Challenges in Southern Africa', South Africa.
- Keppler, R. (2008). "Road Marking Approval Test in Germany." 1st Road Marking Symposium, Intertraffic 2008, Amsterdam, 20p.
- Kiwa Nederland B.V. (2009). "Nationale Beoordelingsrichtlijn voor het KOMO® productcertificaat voor Wegmarkingsmaterialen", Harmonisatie Commissie Bouw van de Stichting Bouwkwiteit, Rijswijk.
- Labuschagne, K. (2011). "Research Group Leader: Intelligent Systems & Traffic Management, CSIR" Pers. Comm. with John de Pont. on 11/7/2011
- Lanino Traffic Markings. (2011). "Lanino Traffic Markings - Specifications." <http://www.lanino.co.za/content.aspx?NavID=1ebea249-b11a-4827-9bff-8b4d9239f3f7>
- New Zealand Transport Agency. (2009). "Specification for Roadmarking Paints" *NZTA M07:2009*, Wellington.

- Nicholls, J. (1995). "Laboratory testing of road-marking materials." *TRL 121*, TRL, Crowthorne.
- ODOT. (2008). "Oregon Standard Specifications for Construction", Oregon Department of Transportation, Salem.
- ODOT. (2009). "Standard Guidelines for Product Review. Longitudinal Pavement Markings - Standard", Salem.
- ODOT. (2010a). "Standard Guidelines for Product Review. Longitudinal Pavement Markings - Durable", Salem.
- ODOT. (2010b). "Standard Guidelines for Product Review. Longitudinal Pavement Markings – High Performance", Salem.
- Perkins, R. (2008). "White Lines Save Lives." 1st Road Marking Symposium, Intertraffic 2008, Amsterdam, 50p.
- Potter Industries Pty Ltd. (2007). "Pavement Marking Systems Field Trial - Results and Guidelines." Potters Asia Pacific, Laverton, Vic.
- Queensland Government. (2007). "Main Roads - Standard Specification MRS11.45 - Pavement Marking", Department of Main Roads, Brisbane.
- RTA NSW. (2007). "QA Specification 3353 Glass Beads (for Application to Road Marking Materials)", Sydney.
- RTA NSW. (2009a). "QA Specification 3351 Road Marking Paint", Sydney.
- RTA NSW. (2009b). "QA Specification 3359 Profile Thermoplastic Road Marking Material", Sydney.
- RTA NSW. (2009c). "QA Specification 3360 Two Part Cold Applied Road Marking Material", Sydney.
- RTA NSW. (2010a). "QA Specification 3356 Waterborne Road Marking Paint", Sydney.
- RTA NSW. (2010b). "QA Specification 3357 Thermoplastic Road Marking Material", Sydney.
- RTA NSW. (2011). "QA Specification R141 Pavement Marking", Sydney.
- Standards South Africa. (1997a). "Road marking materials — Drop on materials — Glass beads, antiskid aggregates and mixtures of the two." SANS 51423:1997, Standards South Africa, Groenkloof.
- Standards South Africa. (1997b). "Road marking materials — Premix glass beads." SANS 51424:1997, Standards South Africa, Groenkloof.
- Standards South Africa. (2006a). "Road markings Part 1: Single-pack solvent-borne paints." SANS 731-1:2006, Standards South Africa, Groenkloof.
- Standards South Africa. (2006b). "Road markings Part 2: Single-pack water-borne paints." SANS 731-2:2006, Standards South Africa, Groenkloof.
- Stoffers, H. (2000). "Development of European standards for Roadmarking." Baltic Roads Organisation 25th Conference, Baltic Roads Organisation, Riga, Latvia.
- The State of Tasmania. (2010). "Roadworks Specification. R64 - Pavement Marking", Hobart.
- Transit New Zealand. (2003). "Specification for Long-Life Roadmarking Materials" *TNZ M/20:2003*, Wellington.
- TxDOT. (2004). "Pavement Marking Handbook", Texas Department of Transportation, Austin.
- TxDOT. (2006). "Departmental Material Specification. DMS - 8200 Traffic Paint".
- TxDOT. (2009). "Departmental Materials Specification. DMS - 8220 Hot Applied Thermoplastic".