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ANNUAL SUMMARY REPORT

Project Title: A20: Scanning and Scoping Technologies that Evaluate the Remaining Service Life of Sprayed Seals (Year 1 - 2014/15)

Project No: 007200

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A20: Scanning and Scoping Technologies that Evaluate the Remaining Service Life of Sprayed Seals (Year 1 ‑ 2014/15)

SUMMARY

Large parts of the Department of Transport and Main Roads (TMR) road network are sealed with bituminous sprayed seals. Increasingly, these seals are left in service longer than the presumed target age for replacement. It is increasingly common across the state to have seals exceeding the target replacement age by more than 30%. This is due in part to budgetary constraints. However, the risks to the integrity of the road infrastructure associated with these seals are largely unquantified, whereas the recent extreme weather and flood events highlighted the potential vulnerability of pavements.

This study explored the potential of measuring bitumen properties relevant to aging and performance during a sprayed seal's service life using non-destructive methods.

The study found that established field testing methods have specific limitations to their application, with distress needing to be observable (which defeats the preventative nature of the method) or overreliance on a crude field test such as the 'screwdriver test' which is hardly a repeatable and reliable test especially for network management purposes.

The study also examined established binder testing technologies but found that they are also unsuited as their application requires sampling and testing of the recovered binder. The methods are also limited because they were developed for application with unmodified binders, whereas modified binders are widely used in Queensland. Changes in bitumen sources also potentially affect their suitability, whereas sustainability is questionable due to the very time consuming nature of the tests and resulting costs.

The search for a non-destructive device or technology focusing on detecting the existence of specific bitumen chemical components created due to bitumen aging did not yield any success. This is because of the complex chemical nature of bitumen.

To advance the objectives of this research, a change in direction is recommended aimed at establishing a new relationship between binder characteristics and performance. The most promising technology involves the removal of binder samples, extraction of the binder using a solvent and testing these in the Dynamic Shear Rheometer using a modified test method. The results, together with field assessment of in situ performance, could provide the means to investigate links between sprayed seal surface age and condition binders.

In addition, extending the scanning to involve industry which has an interest as suppliers and manufacturers, other road agencies and international partners with similar requirements is recommended. This may also reveal whether any prospective technology is available or under development in industry, as this was not evident from the literature review performed during the study.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 Background

Large parts of the TMR road network carry low volumes of traffic. The most economical way to seal such networks is to use sprayed seals.

Currently, TMR and other road agencies adopt Austroads recommended life spans for spray seal surfacings. In Queensland, depending on the location of the network, the expected sprayed seal life ranges from 8 to 12 years (Oliver 2004). However, seal lives in excess of 30% greater than the presumed target age for replacement are increasingly common across the state due in part to budget constraints, whereas the real risk of failure is unknown. In the more heavily trafficked parts of the network, shorter surfacing lives have also been observed (60% of current target lives).

It is critical for asset managers to be able to predict when sprayed seal surfacings may require intervention, preferably well in advance so that adequate resources can be provided to undertake intervention activities. This will allow managers to develop short to medium-term maintenance programs and allow them to budget with a high level of confidence to avoid the risks associated with premature or late resurfacing.

Current methods of estimating likely seal life based on bitumen durability are increasingly of less relevance due to the extent of use and need for modified binders and fabric seals to address performance conditions, including the treatment of badly damaged surfaces. The identification of alternative methods to improve the assessment of sprayed seals would considerably enhance the department’s ability to manage risks, support budget applications and optimise spending.

1.2 Scope

The study is aimed at exploring the potential of measuring bitumen properties relevant to aging and performance during its service life with methods looking beyond the techniques currently used in pavement materials testing, although these and field survey methods are relevant in defining current practice including its limitations.

The study therefore includes:

- A review of the survey and bitumen test methods which are currently used by TMR in its network-level surveys.
- An examination of the devices and technologies which could be potentially adopted by TMR to assess the level of aging on its sprayed seal network.
- Recommendations on a practical approach which could be adopted by TMR immediately to assess the risk of failure associated with its sprayed seal network.

1.3 Structure of the Report

Following this introduction, this report is structured as follows:

- Section 2 summarises the existing Australian practice and evidence related to the oxidation performance of sprayed seals.
- Section 3 describes the attempts to scope desired devices or technologies from those which are currently utilised by TMR and the Australian bitumen industry.
- Section 4 describes studies conducted on chemical components in bitumen and available test methods as well as their suitability for the purpose of this project.

- Section 5 details the chemical components generated by bitumen due to aging effects and their relationship with bitumen rheological properties as well as efforts on scoping desired devices and technologies from this perspective.
- Section 6 explores current Austroads research relating to bitumen aging test methods and assesses the potential of adopting them to meet the challenge associated with TMR's sprayed seal network.
- Section 7 describes the key conclusions and recommendations from this study.

2 HISTORICAL PRACTICE

Sprayed seals have played a significant role in ensuring reasonably long-lasting and cost-effective road pavement solutions for many years. The extensive and continuing use of sprayed seals is testimony to their effectiveness, with Australia, New Zealand and South Africa being amongst the most prolific users of the technology, along with the United Kingdom. Queensland is no exception, with sprayed seals representing the surfacing on almost all of the state road network.

Australian practice in managing sprayed seals has for many years been based on intervening at a time close to the point where bitumen hardening, resulting from chemical reaction with atmospheric oxygen, leads to surface cracking or stone loss. The premise for this is that, once the bitumen begins to crack, the seal is no longer able to waterproof the granular pavement below it, and pumping of fines leading to potholes and further pavement deterioration will commence.

Bitumen hardening is a slow chemical reaction, and the rate at which it proceeds at a particular site depends on bitumen temperature, the resistance of the bitumen to hardening and binder film thickness. The intrinsic resistance of a bitumen to hardening can be measured using the ARRB Durability Test (AS/NZS 2341.5 1997), and a minimum bitumen durability value is specified by a number of Australian road agencies.

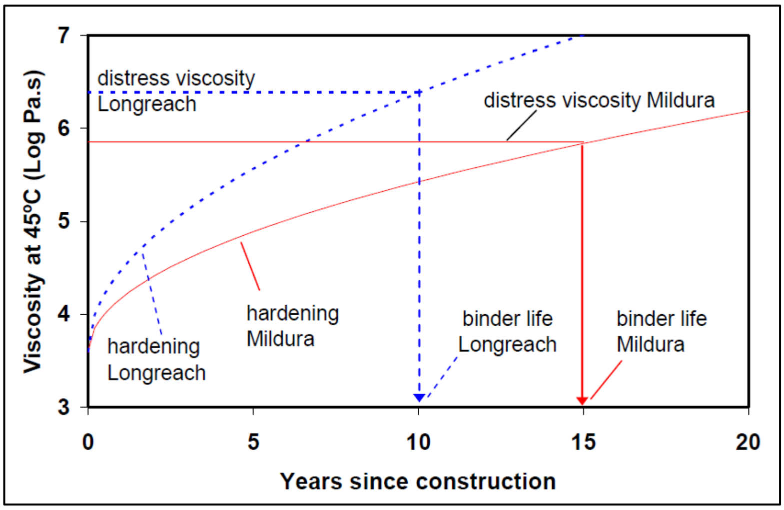
A model to estimate bitumen hardening, and the likely life of a seal, was originally developed by Oliver (1987). It comprises the following two main components:

- *Rate of hardening*: information from 10 full-scale road trials and 13 non-trial sites located in different areas of Australia was used to establish a bitumen hardening model. The non-trial sites were ‘normal’ seals and reseals which had not been placed as road trials but which had been sampled and the binder viscosity tested at some stage of their life. In all, a total of 124 data points covering 45 different types of bitumen were used to construct the model. Inputs into the model were seal age, temperature at the seal site and the durability of the bitumen in the seal. The model was subsequently updated and expanded to include binder film thickness by including surface seal aggregate size as an input (Oliver 2004).
- *Distress viscosity*: the critical (or distress) viscosity was determined based on a sample of sites selected by road agencies which were just commencing to show distress due to ageing. Twenty-seven samples were obtained and the data was used to develop a model (Oliver 1990) based on the daily minimum temperature (obtained from meteorological records) close to the seal site. The evidence showed that the viscosity level at which seal distress occurred in a cool climate area, such as Tasmania, was likely to be lower than the distress viscosity level in a warmer climate area, such as Darwin. In other words, the viscosity level at which a seal shows distress depended on climate as well as other factors.

Combining the binder hardening and distress viscosity models permitted the prediction of binder life, or more particularly the intervention point for resealing, in different climatic areas of Australia.

An example of the use of the model is shown in Figure 2.1, which shows predicted binder lives in Mildura, Victoria, and Longreach, Queensland (Oliver 2004). The Mildura plots are shown as continuous lines and the Longreach plots as dashed lines. As indicated in Figure 2.1, the binder hardens more rapidly in Longreach than in Mildura but this is compensated for, to some extent, by the distress viscosity level in Longreach being higher than in Mildura.

Figure 2.1: Prediction of maximum seal life for sites at Longreach and Mildura



Source: Oliver (2004).

In a further refinement to the model (Oliver 2006), a risk factor was introduced which aimed to take account of information obtained during the development of the original model. This indicated that some agencies intervened at an earlier stage than others. This was based on factors such as the likelihood of damage to the pavement structure resulting from moisture ingress through a cracked seal, the importance of the road, or experience with the performance of aged surfacings.

These factors can be expressed in terms of the risk associated with delaying sealing beyond the first indications of distress. For example, in a low rainfall area with low traffic and strong, moisture-resistant bases, it may be possible to delay resealing for five years or more after the first signs of cracking or stone loss are observed. In areas of high rainfall or irrigated or high water-table areas, however, it may be necessary to seal as soon as the first signs of cracking appear in order to avoid rapid deterioration of the surface and possible damage to the base. For strategically important roads, carrying substantial traffic, a strategy of resealing before any distress is visible may be preferable.

It was concluded that, in general, state road agencies tended to intervene earlier than local government agencies. The analysis of the responses to a questionnaire sent to state and local government agencies in Australia and New Zealand is provided in Oliver (1999). This indicated that, for agencies which recorded seal age, the average life of a 10 mm seal was 9.8 years for Australian state road agencies and Transit NZ, and 12.1 years for Australian and New Zealand local government agencies.

A scale of 1 (very low risk) to 10 (very high risk) was used and the following new combined model (Equation 1) was developed to estimate the years to reach critical viscosity:

$$Y = \left(\frac{0.158 * TMIN - 0.107 * R + 0.84}{0.0498 * T - 0.0216 * D - 0.000381 * S^2} \right)^2 \qquad 1$$

where:

Y = years to critical viscosity from year of application of the seal

T = the average temperature of the site (ºC), calculated as the mean of the annual daily minimum (TMIN) and the annual daily maximum (TMAX) with the values obtained from meteorological records

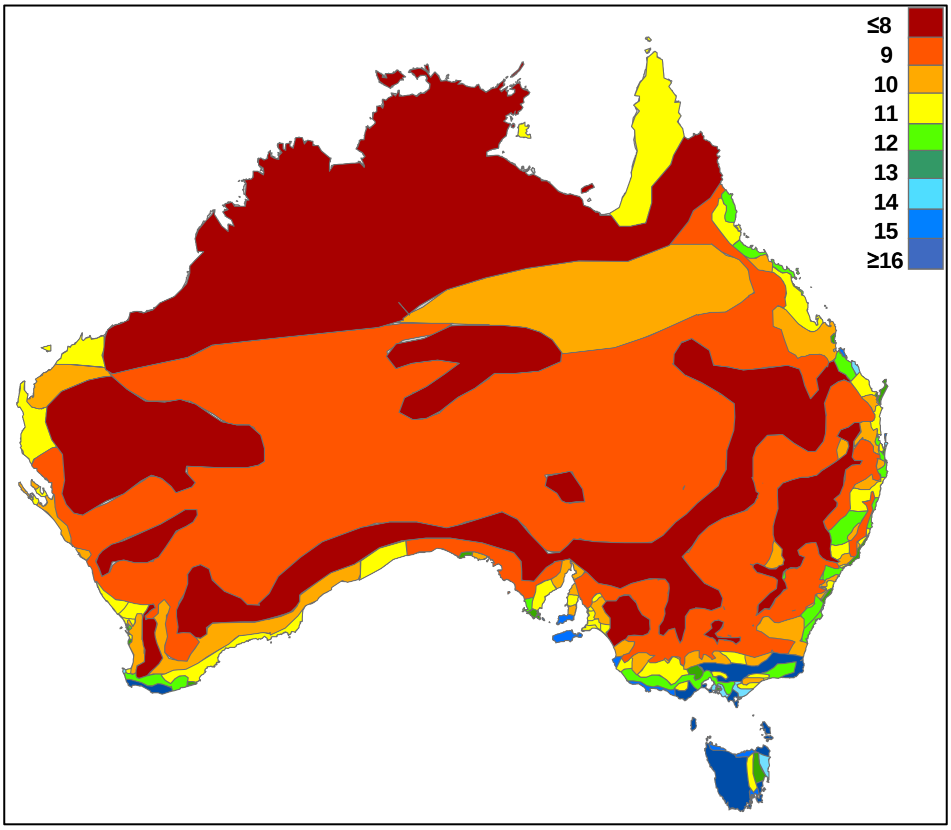
R = risk factor

D = the ARRB Durability Test result (days)

S = nominal seal size (mm)

A map of estimated Australian seal lives (assuming a state road agency case) is presented in Figure 2.2 (Oliver & Boer 2008), with large areas of the country shown with seal lives of 8 years or less but these are generally high temperature areas where the population density is low and there are comparatively few roads. In some areas in the south-east portion of the continent, seal lives are greater than 16 years.

Figure 2.2: Estimated seal lives in different temperature regions in Australia (durability 9.5 days, seal size 10 mm, risk factor 6)



Source: Oliver and Boer (2008).

The Oliver 'seal life' models (Oliver 1987, 2004 and 2006) have been considered a good first cut and are applied by asset managers throughout Australia, including in Queensland despite the fact that bitumen durability is not a requirement of the local specification. Target optimum seal cycles in Queensland are currently set on a region basis and range from 8 to 10 years (Department of Transport and Main Roads 2010), with shorter lives expected in hotter and drier inland regions, where minimum temperatures are also lower.

Based on the data reported by Oliver (2006), the average seal lives estimated for two locations in Queensland are presented in Table 2.1 based on the new model, with risk added, and for the original model.

Table 2.1: Intervention time (years) for a range of risk factors at two sites in Queensland

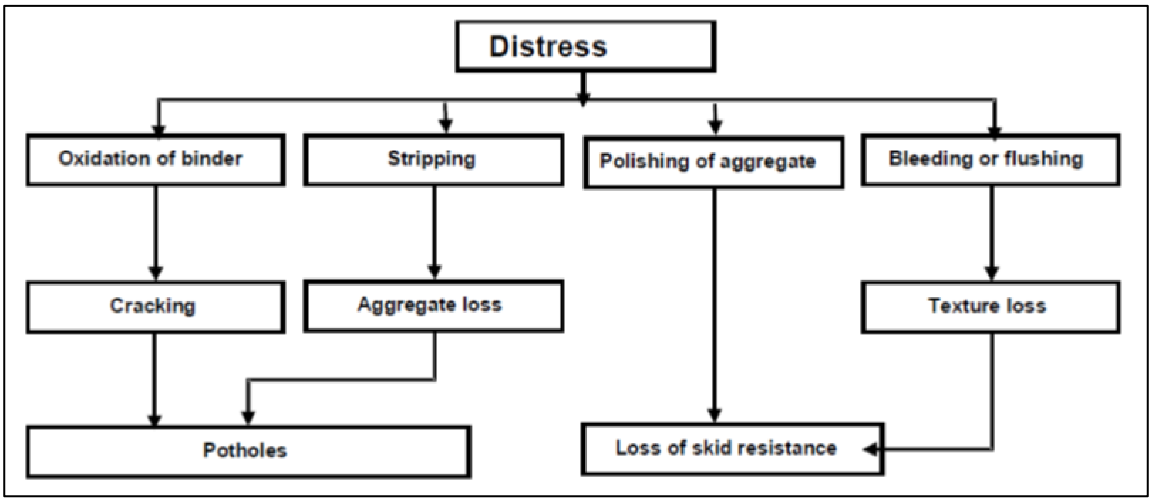
Risk factor	3 (typical LG)	4.5 (previous model)	6 (typical SRA)
Charters Towers	11.3	10.2	9.1
Brisbane	13.5	12.1	10.8

The emphasis in the seal life model is the estimation of the maximum expected seal life, provided premature distress does not occur. Where the standard of construction is of high quality and the design is fit-for-purpose then this is likely to hold true and therefore such estimates can be considered as a useful input to the management of sprayed seals. However, it is important to note that intervention may be required if surface distress occurs earlier, e.g. as a result of traffic-related factors such as over-stressing, reflection cracking, fatigue or structural failure of the pavement.

The practice of resealing close to the point of critical viscosity is widely referred to as 'birthday seals', which suggests that binder age is the sole criterion for intervention. This is, in fact, not the case, with the underpinning scientific basis simply being a 'rule of thumb' for screening and planning purposes; it is not a decision criterion.

In practice, a range of factors contribute to shortening seal lives. Figure 2.3, from Austroads (2009a), provides a graphic summary of the most common distress modes associated with sprayed seals. The load-bearing capacity of the upper and lower pavement layers may be added to this list as this can lead to premature deterioration, as can the reflection of distress from underlying layers. In asset management practice the latter factors are considered as primary sources of road deterioration, along with the disintegration of a surface resulting from stone loss or cracking and factors which contribute to reduced surface texture and therefore skid resistance.

Figure 2.3: Distress modes for sprayed seals



Source: Austroads (2009a).

3 CURRENT TESTING DEVICES AND TECHNOLOGIES

3.1 Introduction

TMR has a number of established network-level survey and field assessment methods as well as laboratory-based test methods in place. These methods have been used regularly by TMR to fulfil various tasks. A quick win could be achieved if any of these methods were suitable for the purpose of this project.

3.2 Network-level Survey Devices

TMR surveys its network on a regular basis using a multi-laser profilometer (MLP). The MLP is capable of collecting network condition indices such as roughness, rutting, and macrotexture. The same survey vehicle is equipped with a digital imaging system which can capture images of surrounding assets during the survey through roof-mounted digital cameras, and vertical cameras to help detect surface distress, such as cracking. In addition, a laser crack measuring system (LCMS) has also been introduced for network-wide surveys as part of the ARRB Hawkeye System and in the Traffic Speed Deflectometer (ARRB Group n.d.a. & ARRB Group n.d.b.).

3.2.1 Macrotexture

Among the condition indices collected by the MLP, macro-texture level is the one which is closely linked to sprayed seal performance.

The macro-texture (or texture depth) represents the space between aggregate particles, otherwise referred to as texture, and is an indication of the volume through which water may escape from the interface between a tyre and the road surface. It is thus an important component of skid resistance, for without sufficient texture depth to allow the removal of water, aquaplaning may occur. The surface texture profile allows the vehicle tyre tread to deform, so creating hysteresis forces that contribute greatly to the total available level of friction provided by a road surface (Austroads 2009b).

Reduced texture depth occurs through wear and stone embedment, and can develop quickly as a result of flushing/bleeding in hot weather leading to skid resistance deficiencies. These are usually afforded high priority, as they can contribute significantly to the crash risk, and hence the level of safety at a location.

However, it should be noted that although macrotexture plays an important contributing role in determining the skid resistance level associated with the sprayed seal surface, it has no direct association with the performance relating to bitumen aging. However, low texture depth can be a determining factor to define the remaining life of sprayed seal surface and as a main indicator for resurfacing (Transit New Zealand 2005 and Patrick 1999).

3.2.2 Surface Defects

The digital imaging system not only captures assets surrounding surveyed roads, it also records defects on the road surface. This allows a post-survey rating process to identify and report the type, location, quantity and severity of these defects. Commonly reported defects include cracking, potholes, edge breaks, etc. These defects, in conjunction with network condition indices, have been effectively utilised by asset managers to propose treatment programs.

With the introduction of the LCMS the detection of cracks should be more reliable and trends consistent from year to year. This improves the likelihood of early detection. However, it should be noted that even this method relies on the appearance of distress, which defeats the preventative nature of this study, the aim being to predict the timing of likely distress from binder properties.

3.3 Field Testing Methods

Besides the MLP and LCMS, the review identified a field-based evaluation method called the 'screwdriver test'. This test method has long been used by TMR engineers to assess the condition of sprayed seals. The procedure for this test involves retrieving aggregates on site using a screwdriver and observing the height of the binder on the retrieved aggregates. This allows the engineers to judge the likelihood of a sprayed seal having stripping issues in the near future. The common rule is, if the bitumen covers greater than two-thirds the height of the aggregate, the chances of the sprayed seal surface stripping is considered to be low. Engineers also assess the 'wetness', or stickiness, of the attached bitumen to judge its level of aging.

Despite the popularity of the screwdriver test among the field engineers, it is obvious that it is a highly subjective method which is time-consuming and demands experienced assessors, making it unattractive for network-level asset management tasks.

3.4 Laboratory Bitumen Durability Testing Method

There are a number of laboratory test methods employed by road agencies to assess the rheological properties of bitumen. The ARRB Bitumen Durability Test is one of these methods, and its basis is described earlier (Section 2). A minimum durability for bitumen is required in a number of Australian states and territories, including Victoria, South Australia, Western Australia, Tasmania and the Northern Territory. However, bitumen durability is not a requirement of specifications applied in Queensland and New South Wales.

This test method was developed around four decades ago and has been broadly used to assess the durability characteristics of the bitumen before it is accepted for road construction purposes.

However, a number of issues regarding the suitability of this test to assess the bitumen aging properties have been raised by a recent Austroads study (Austroads 2013):

- The equipment required for the method (i.e. ageing oven and viscosity measuring device) are Australian-specific and supplied/maintained on an 'as needed' basis only. The number of users in Australia is small and procuring of the necessary equipment (or equipment components when the devices need to be repaired) is not sustainable due to the lack of commercial interest.
- The test procedure is rather complex and, more importantly, takes a long time to perform (over two weeks depending on how durable the binder is). If bitumen is imported, rather than manufactured locally, testing time and equipment availability can cause logistical problems to overseas suppliers. In the next few years, it is expected that only a small proportion of the bitumen used in Australia will be manufactured locally.
- The method was originally developed for the testing of bitumen only. It is therefore considered inappropriate for testing of other binders, particularly polymer modified binders (PMBs). Due to increasing traffic loads, the use of these high-performance binders in sprayed seals is now common practice, with almost 50% of sprayed seals on state-controlled roads in Queensland incorporating a PMB (Department of Transport and Main Roads 2016).
- The durability test parameter is obtained from viscosity results measured at a temperature of 45 °C. Concerns about aged/hardened binders are generally related to their resistance to cracking at low temperatures (e.g. 5 °C). Therefore, the current 'binder viscosity testing regime' may not be an ideal method to assess the low-temperature performance of binders.

These issues have been noted by the Australia highway engineering community and the community has indicated that a new durability test is needed to replace this method. In order to meet this requirement, a trial procedure has been developed which includes use of a pressure aging vessel (PAV) and a dynamic shear rheometer (DSR) to prepare and test samples, with the sample preparation and test cycle reduced to around three days (Austroads 2013).

Furthermore, to provide a basis for practical application, there is a need to determine the DSR flow test characteristics of both fresh binders subjected to PAV preparation and recovered[1], in-service binders, and to correlate the measured characteristics with field performance. This would be a step towards building an evidence base using more complex rheological tests to assess the likely in-service performance of sprayed seals containing either straight-run or modified binders.

3.5 Summary

According to the information outlined above, it is obvious that the established methods have specific limitations in their application, with distress needing to be observable, or reliance on a crude field test and increasingly scarce experienced practitioners. This defeats the preventative nature of the study.

Current binder testing methods for ‘ageing’ of binders are also very time consuming and can only be used for unmodified bitumen, whereas PMBs are very common on the Queensland state road network.

Whereas recent advances in binder preparation and testing methods show considerable promise, practical application would require the development of a comprehensive evidence base drawing on fresh and recovered binders and field observations to establish a new set of performance relationships. The aim would be to replace the current technology and evidence base with solutions applicable to the modern binders used in Queensland.

[1] Samples recovered from in-service roads would be subject to preparation using a bitumen extraction process (Austroads 2015) prior to testing in the DSR.

4 SCOPING A DEVICE FROM A BITUMEN CHEMICAL COMPOSITION PERSPECTIVE

Since the attempts to identify a device or technology from established test methods which focused on the physical properties or the apparent defects in a sprayed seal did not yield any success that was immediately applicable, it was reasonable to broaden the study to examine methods which address the chemical composition of bitumen[2].

4.1 Bitumen Chemical Components

Bitumen is a complex material; therefore, it is important to identify its chemical composition and the relationship of this to performance.

Bitumen is the residual product from the distillation of crude oil in petroleum refining (Asphalt Institute and Eurobitume 2013). It is comprised of a complex mixture of organic molecules which vary widely in composition, including organic compounds containing a high proportion of hydrocarbons with high carbon numbers (Asphalt Institute and Eurobitume 2013). The molecules present in bitumen are combinations of alkanes, cycloalkanes, aromatics and hetero-molecules containing sulphur, oxygen, nitrogen and heavy metals (Read & Whiteoak 2015).

It has been widely accepted that, although bitumen is a widely used engineering material and is produced to meet a variety of specifications based on physical properties, the durability of bitumen and, therefore, the bitumen and aggregate mixture is largely determined by the physical properties of the bitumen. These, in turn, are determined by its chemical composition (Petersen 1984).

It is important, therefore, to understand the chemical components of the bitumen and identify those which have a direct correlation with bitumen durability performance.

4.2 Bitumen Components Characterisation

Despite the complexity of the bitumen components, bitumen characterisation is based on four broad classes of compounds, namely, saturates, asphaltenes, resins and aromatics. The definition of these four components according to Asphalt Institute and Eurobitume (2013) is as follows:

- Saturates predominantly comprise the straight and branched-chain aliphatic hydrocarbons present in bitumen, together with alkyl naphthenic and some alkyl aromatics.
- Asphaltenes are black amorphous solids containing mostly carbon and hydrogen, and some nitrogen, sulphur and oxygenHighly polar aromatic materials. Asphaltenes have high viscosity or stiffness at ambient temperatures and are responsible for the overall stiffness of bitumens. They can be precipitated with n-heptane and are sometimes referred to as n-heptane insolubles.
- Resins are dark-coloured, solid or semi-solid, very adhesive fractions of relatively high molecular weight. They are dispersing agents for the asphaltenes, and the proportion of resins to asphaltenes to a degree governs the rheological behaviour of bitumen.
- Aromatics comprise the lowest molecular weight naphthenic aromatic compounds in bitumen, and represent the major proportion of the dispersion medium for the peptised asphaltenes. They constitute 40–65% of the total bitumen, and are dark-brown viscous liquids.

It has been identified that hetero-atoms which are typically found in the asphaltene and resin components have a strong influence on the physical properties and performance of bitumen

[2] Australian terminology and spelling is used throughout in the text of this report, with the exception being the retention of American terminology and spelling in figures/illustrations sourced from the literature and in reference titles etc.

(Asphalt Institute and Eurobitume 2013). Although it is generally accepted that the role of resins in bitumen is to stabilise the asphaltenes, the exact mechanism of such stabilisation remains unclear.

Against this background, the focus of the project turned to scoping a device or technology which could be adopted or further developed to detect the amount of resin and asphaltenes in bitumen on site in a quick and effective fashion. Such a device or technology could meet the challenges facing TMR and give network managers greater confidence when proposing resurfacing programs.

4.3 Scoping a Device to Test Bitumen Chemical Composition

4.3.1 Survey Device Characteristics

Prior to the scoping work, it is important to define the key characteristics of the desired survey device or technology.

Based on the properties of existing network condition survey devices, it is obvious that the desired device should be able to scan the network in a quick, effective and non-destructive fashion. In addition, the collected results should be interpretable and have a direct correlation with the performance of the in-place binder.

4.3.2 Scoping a Device or Technologies

Since asphaltenes and resin play a key role in the remaining life of a spray sealed, the device should first have the capacity to quantify these two elements.

The study explored the methods adopted by researchers in several countries to identify these two chemical components. In all cases, the identified current test methods are laboratory based.

A detailed review of testing procedures indicated that one key procedure involved in the tests was to recover the asphaltenes or resins. This procedure is very tedious as it involves precipitating the bitumen samples using the solvent n-heptane followed by a coagulation process before the asphaltenes or resin can be recovered by filtration (Austroads 2015). In addition, the test samples are required to be placed in a stable environment.

It is unlikely that a device exists which could complete these procedures on site, recognising also the amount of time required to complete the test, and it would be impracticable to roll out a test of this type on a network scale. Therefore, a decision was made to stop the study from this perspective.

5 SCOPING A DEVICE USING FOURIER TRANSFORM INFRARED SPECTROSCOPY

5.1 Bitumen Aging Mechanism

The literature review revealed that the aging process in sprayed seals usually commences in a top-down fashion. The chemical species generated due to aging would therefore be expected to be present on the top of the surface, and their concentration level at the surface would therefore be expected to reflect the ageing level of the bitumen.

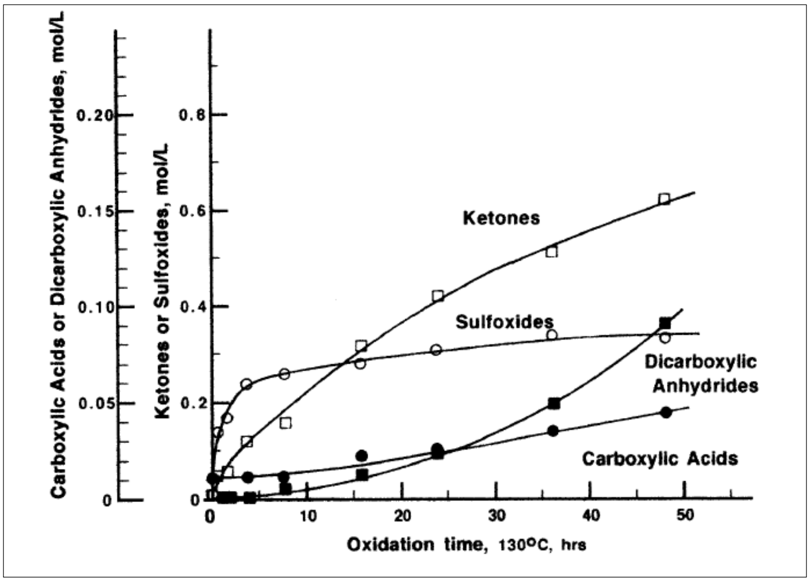
The aging effect of bituminous binders is one of the key factors influencing the remaining life of sprayed seals. The process of aging involves chemical and/or physical property changes that usually make bituminous materials harder and more brittle, which promotes cracking, and less adhesive which promotes stripping, and therefore increases the risk of failure.

Bitumen aging concerns the physical property changes that occur due to changes in bitumen chemical composition as time elapses. These changes are produced by the interaction of intrinsic and extrinsic variables associated with short and long-term aging. It is widely accepted that binders in road surfacing experience gradual changes in their rheological, cohesive and adhesive properties during their service lives. The estimation of surface life is predicated on the basis of the mechanism of bitumen hardening to a point where its viscosity causes embrittlement and thereby cracking or detachment of the bitumen (Austroads 2010).

Bitumen aging mechanisms consist of volatilisation, oxidation and steric hardening. A major product of bitumen aging is the carbonyl functional group, of which ketones and sulphoxides are the major products of the oxidation processes.

Figure 5.1 illustrates the relationship between the oxidation time and amount of oxidation products determined by Fourier transform infrared spectroscopy. It is evident that the concentration level of ketones is both highest and varies most linearly of all the chemical species with the aging period whereas, for the example shown, the production of sulphoxides initially increases quickly but the rate levels off over time.

Figure 5.1: Example of oxidation products formed as a function of time in thin-film laboratory aging at 130 °C

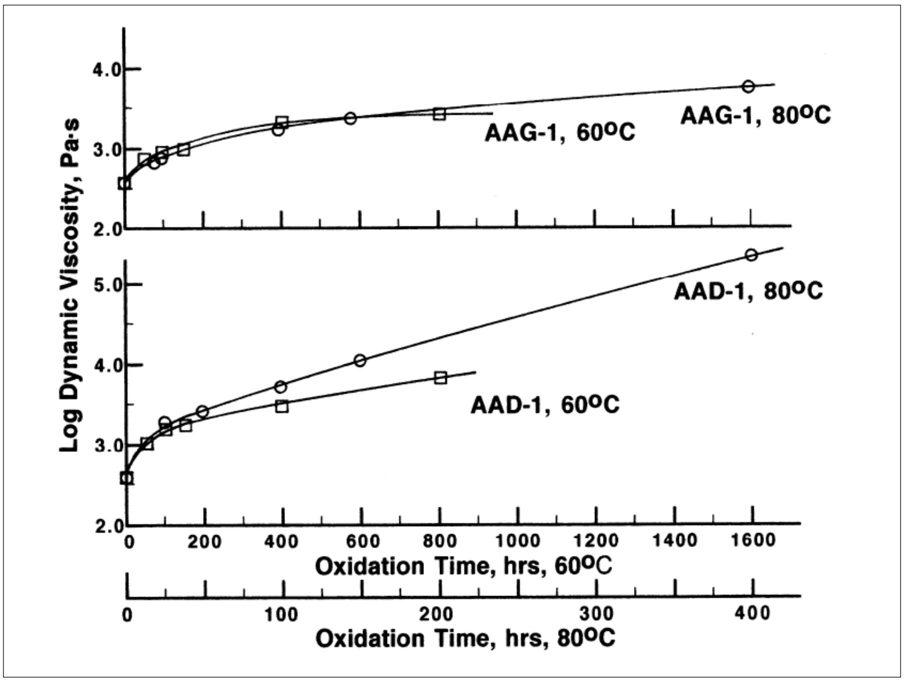


Source: Petersen et al. (1993)

Branthaver et al. (1993) reported that bitumen with a higher sulphur content is less sensitive to oxidative age hardening, whereas Petersen et al. (1993) have shown that the ratio of sulphoxides to ketones formed on oxidation increases with increasing sulphur content, with sulphoxides being formed at the expense of ketone formation. The conclusion drawn from extensive research on the subject was that sulphoxides in bitumen are effective antioxidants and reduce the rate of hardening.

The rate of oxidative hardening, however, has also been shown to differ depending on both sulphur content and temperature as illustrated in Figure 5.2, where the relationship between the oxidation time and the dynamic viscosity level of the bitumen is shown for two sources studied in the U.S. Strategic Highway Research Program (SHRP). In this figure, bitumen AAG-I is a highly compatible bitumen with a well-dispersed microstructure and a low sulphur content (1.3%), while bitumen AAD-1 is at the other end of the compatibility spectrum with a high sulphur content (6.9%). The time scales have been time-temperature shifted to offset the effect of temperature on the increase in oxidation rate so that changes in kinetics as a function of temperature can be visually compared.

Figure 5.2: Effects of temperature and component compatibility on oxidative aging characteristics



Source: Petersen et al. (1993).

For the lower sulphur content bitumen (AAG-1) the rate of change of viscosity is relatively low between 60 °C and 80 °C, whereas in the higher sulphur content bitumen (AAD-1) the rate is significantly higher after the initial increase at low oxidation times. This further illustrates the role of different oxidation products and environments, and in this case the sulphur content of the source bitumen and the temperature regime to which it is subjected, in determining the rate and ultimate level of oxidation.

The different response to temperature of the two samples has been used to explain why bitumen made from a high sulphur content crude hardens and becomes brittle more rapidly in a hot climate, but can perform quite well in a more moderate climate. With regard to age hardening, Petersen et al. (1993) also concluded that the maximum pavement temperature reached during hot days is more critical to eventual age hardening than use of average temperatures.

5.2 Scoping a Device or Technology

Since a correlation between the concentration level of ketones determined using FTIR and bitumen viscosity level has been found, whilst acknowledging the complications associated with multiple factors, the review shifted focus to scope a suitable device or technology from this viewpoint.

Western Research Institute regularly measures the concentration levels of the carbonyl functional groups in bitumen using a laboratory-based device called the Fourier-transform infrared (FTIR) spectrometer (Western Research Institute 2010).

FTIR can determine the existence of different chemicals by detecting the absorption peaks which correspond to the frequencies of vibrations of the bonds between the atoms making up the materials. Because each different material has a unique combination of atoms, different chemicals will produce different infrared spectra. Infrared spectroscopy can be used to detect the presence of a large number of specific chemical groups in a material, though not all. In addition, the height of the peaks in the spectrum is a direct indication of the number of particular chemical groups that are present in a material (Thermo Nicolet Corporation 2001). FTIR is therefore considered to be one of the test methods which could be suitable for the purpose of this project.

However, the study also noted that the concentration level of carbonyl function groups seems to vary significantly if the origin of the bitumen is different even though they are subjected to the same aging effects.

Further review discovered that a number of studies (Lau et al. 1992 & Petersen et al.1993) have concluded that the correlation between the concentration level of carbonyl function groups and aging effects is dependent on the source of the bitumen. In addition, Thomas (2002) has shown that the presence of moisture during aging in a pressure aging vessel (PAV) can also influence the rate of oxidation.

In an attempt to provide a non-destructive solution for obtaining data on aged in-service asphalt, the Western Research Institute (2010) also reported attempts to put an FTIR device on the bottom of a survey vehicle. However, no measureable readings were obtained. It is also understood that successful use of the FTIR requires completely dry conditions (with laboratory FTIR equipment having the means of completely drying the internal workings of the FTIR), and therefore this technique is likely to be unsuccessful outside in wet (or humid) air.

A number of bitumen industry personnel were consulted and it was discovered that it is not common practice for bitumen manufacturers to indicate or label the origin of the bitumen when it is supplied to clients. In addition, the practice of blending bitumen from different sources is common in Australia, which no doubt further complicates this issue. The study did not find any registration system or similar which is in place to record the source of the bitumen or the locations where such bitumen was used.

With the evidence obtained from the review, it is obvious that despite the fact that the technology appears to be promising as it would allow the detection of the carbonyl functional groups in a quick and non-contact fashion, any results obtained by this method would be unlikely to provide any accurate information on the remaining life of a sprayed seal.

6 CURRENT BITUMEN PERFORMANCE TESTING STUDY

Having established that existing devices or technologies which utilised established test methods or through application of FITR technology could not yield any success, the focus of the study shifted to recent Austroads research projects.

The review of Austroads studies relating to bitumen performance testing identified that Austroads is investigating the long-term aging characteristics of sprayed seal binders using laboratory testing methods.

Tests that have been considered have included the use of the Dynamic Shear Rheometer (DSR), the Bending Beam Rheometer (BBR), and the Direct Tension Test (DTT) and Extensiometer Critical Tip Opening Displacement (CTOD) test (Austroads 2013). Recent Austroads research has identified that the DSR flow test appears to be the most promising in terms of future use as a long term oxidative aging test in Australia, whereas the CTOD in its current form is unlikely to be suitable (Austroads 2014).

The main advantages of the DSR flow test are:

- the DSR test requires a short testing time (about 20 minutes of loading time) and employs a simple operational procedure
- the test can be performed at low testing temperatures, i.e. 15 °C (or 20 °C)
- a single test specimen requires less than 2 g of bitumen
- although a standard test method does not yet exist, a trial test method is available and the testing device is available at both TMR and ARRB laboratories.

The key advantage of the DSR test is the amount of bitumen required to perform the test. This could allow the test to be performed on bitumen samples retrieved from sites representing different properties of the TMR sprayed seal network.

It is also practicable for TMR to collect bitumen samples from a series of representative sub-network sites, and to subject these to DSR testing to develop the relationship between the rheological characteristics of bitumen and its age. A representative sub-network could be selected which covers a wide range of parameters, such as environment zones, pavement structure, road function, etc.

Such a study would allow the life expectancy of sprayed seals on different parts of the network to be assessed and analysed, with the possibility that binder test results could be related to sprayed seal performance. The outcome of the study would enhance the reliability of the TMR pavement management system and enable the asset managers to make rational decisions while planning resurfacing programs so that premature or late sealing/renewal and their associated risks and damage can be avoided. It would also provide a more sustainable basis for seal management, and reduce reliance on the judgement of increasingly scarce experienced practitioners.

The bitumen sampling and testing program would be designed to include both DSR flow tests (Austroads 2013) with reported parameters including the measured yield energy and stress ratio, and the reporting of conventional DSR test properties including dynamic shear modulus and phase angle (see AASHTO test method T315 (AASHTO 2012)) of non-PMB binders.

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7 CONCLUSIONS AND RECOMMENDATIONS

This study attempted to scope the desired devices or technologies from four different aspects, namely:

- established surface assessment devices and binder testing technologies
- bitumen chemical components (using solvent separation methods and FTIR)
- recent developments in the characterisation of the physical properties of binders.

The study found:

1. Established field methods have specific limitations in terms of their application, with distress needing to be observable (which defeats the preventative nature of the study) or overreliance on a crude field test such as the 'screwdriver test', which is not a repeatable and sufficiently reliable test for network-level asset management.
2. The established binder test method for 'aging' purposes is Australian-specific and supplied and maintained on an as-needed basis and is very time consuming, and consequently is at risk of being unsustainable. The method was originally developed for the testing of bitumen only, and is inappropriate for testing of other binders, particularly PMBs which are increasingly being used, with almost 50% of sprayed seals on state-controlled roads in Queensland incorporating a PMB. Concerns also exist on the relevance of the test temperature of 45 °C for determination of viscosity characteristics, whereas age hardened binders in Australia are generally related to their resistance to cracking at low temperatures (e.g. 5 °C).
3. Due to the complex chemical nature of bitumen, a non-destructive device or technology could not be identified as practicable and fit for the purpose of this project. It is believed that this will be a long-term task which requires cooperation with other government agencies and industry players who have a vested interest in the development of such technology. Although prospective technology may be available or under development in industry, this was not evident from the literature review performed during this study.
4. The most promising technology involves the removal of binder samples, extraction of the binder using a solvent and testing these in the Dynamic Shear Rheometer using a modified test method and conventional tests. The results, together with field assessment of in situ performance, could provide the means to investigate links between spray seal surface age and condition. This would allow TMR to further evaluate the risk associated with its sprayed seal network in a quantitative and systematic manner. Employing such a method would involve dividing the network into various sub-networks with respect to parameters such as environmental zones, road hierarchy, traffic level, pavement type, surface age, etc. and obtaining bitumen samples from such locations. Condition assessments of cracking, ravelling, bleeding, rutting, would be undertaken at the same locations. However, such a study would need to accept the fact that many roads have received multiple seals; reseals are invariably applied to relatively short lengths and the bitumen sources, therefore properties, frequently change.
5. Alternatively, or in parallel, it is recommended that the scanning is extended to involve industry which has an interest as suppliers and manufacturers, other state road agencies and international partners with similar requirements.

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