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Abstract

The current Austroads specification for sprayed seal binders provides guidance on the choice of binders considered suitable for the alleviation of reflection cracks through a seal. However, some of those binders have proved problematic for a variety of reasons, including the high potential for early-life stripping failure if they are not applied in ideal conditions.

This paper discusses shortcomings with the current Austroads specification for bituminous sprayed seal binders and details the development of a new binder for the alleviation of reflection cracks in sprayed seals. The objective in developing the new binder was to maximise the potential to alleviate reflection cracking whilst also maximising the stone adhesion and retention capabilities of the binder. Development of the new binder required laboratory scale testing of prospective binder formulations, which in turn required the development of laboratory-scale tests that could be used to determine both the relative resistance to reflection of cracks through a seal and the relative adhesion properties of different binder formulations.

Introduction

Although standard bitumens deliver satisfactory performance in the majority of situations, there is an increasing need to use polymer modified binders (PMBs) to cope with the increasing demands on bituminous surfacings.

PMBs were introduced to the Australian market in the 1980s and their use has increased substantially over the years. The acceptance of PMBs has been driven by the requirement for more durable maintenance treatments and a need for improved binder properties to cope with increased traffic stresses on surfacings (Oliver 1990).

This paper was presented by Stuart Dack, Bitumen Marketing & Product Development Manager for Puma Energy (Australia) Pty Ltd at the 5th Australian Road Engineering and Maintenance Conference held in Melbourne in March 2010.
Polymer modifiers

The predominant polymer modifiers used in Australia today are styrene-butadiene-styrene (SBS), ethylene vinyl acetate (EVA), polybutadiene (PBD) and crumb rubber.

Styrene-butadiene-styrene (SBS) block co-polymer

SBS is one of the most common polymer types used in PMBs. SBS is highly elastomeric and this property is conferred to products which incorporate SBS. As with all polymers, SBS is available in many different forms. The polymer chain length can vary, as can the styrene to butadiene ratio, although typically polymers with 30% styrene are used. The polymer is also available as a linear or radial configuration. Australian bitumens are generally not very ‘compatible’ with SBS polymer and the addition of aromatic ‘combining agents’ is usually required to assist in the dispersion of the SBS polymer through the bitumen. In the past, some types of combining agents have given rise to unacceptable levels of fuming during the laying of asphalt. As a consequence, a code of practice was published (AAPA 1998) to provide guidance in the manufacture of these binders and to advise on good practice when mixing and laying asphalt containing SBS-modified binders.

Initially in Australia, SBS-modified PMBs used in sprayed sealing were manufactured from a ‘concentrate’ consisting of about 15% SBS polymer. It was then common practice to dilute the concentrate with Class 170 bitumen at standard rates of, for example, 10%, 20%, 33.3%, 40% and 50%. This led to the common use of PMBs with final SBS concentrations of 1.5%, 3%, 5%, 6% and 7.5%.

Sprayed seals constructed with SBS-modified binders require careful application due to the potential for stripping of the seal resulting from poor adhesion to the sealing aggregate. This is particularly a problem for SBS concentrations of 6% or higher, but can be experienced at lower SBS concentrations, particularly in less than perfect sealing conditions.

Ethylene vinyl acetate (EVA) co-polymer

Like SBS, there are many types of EVA polymers available. EVA can contain different ratios of ethylene to vinyl acetate and can have different molecular weights, i.e. different polymer chain lengths. Typical vinyl acetate levels are 18% and 33% for EVA polymers used to modify bitumen. EVA polymers are considered to be plastomeric and act by making the PMB stiffer than conventional bitumen – a feature that is particularly useful in asphalt where they find most use. However, stripping, possibly due to brittle fracture of the PMB, has been a problem in some sprayed seal applications (Holtrop 1990) and their use in sprayed seals is now rare.

Crumb rubber

Crumb rubber, or scrap rubber, is available as a result of the reprocessing of old car and truck tyres. The effect of its digestion in bitumen depends on the source of the crumb rubber, the way it was comminuted, its particle size and its content in the bitumen. Commercially available crumb rubber consists of either styrene butadiene rubber (SBR) or natural rubber, depending on the source. Crumb rubber also contains fillers, carbon black and aromatic extender oils, amongst other additives.

Crumb rubber digestions usually require blending on site as the rubber particles will rapidly separate from the blend. Other issues to be considered when using crumb rubber blends include the need to regularly clean out sprayers due to build-up of crumb rubber, premature wear and damage to sprayer pumps, the need to use different spray nozzles to those used for Class 170 bitumen and the need for the binder to be heated to higher temperatures than alternative binders.

Polybutadiene (PBD)

Polybutadiene is an elastomeric polymer and, like other polymers, is available in a range of molecular weights and microstructures. When properly incorporated into bitumen, it produces a tough and strongly cohesive and adhesive binder. PMBs modified with PBD do not require the addition of the combining agents commonly used in the manufacture of SBS-modified binders.

PMBs utilising PBD were introduced to Australia in 1991 (Dack 2008). The first commercial PBD-modified binder was a spray grade called OLEXOBIT SAM. Today this product is specified under grade S35E of the current Austroads specification (Austroads 2006a).

A unique property of the PBD-modified sprayed seal binder appears to be its adhesive qualities, which provide increased resistance to early-life stripping of a sprayed seal. Field experience has shown that the adhesion characteristics of PBD-based S35E binders are superior to the SBS-based S15E and S20E binders (Maccarrone et al. 1997).
Austroads bituminous binder specifications

National specifications for PMBs were published in Australia for the first time in 1992 (Austroads 1992). The various grades included in this first specification were developed around products that were in common use across Australia at the time. The grades specified for sprayed sealing included five grades of SBS-modified PMBs and three binders modified with crumb rubber. The SBS-modified binder grades represented a progression from low levels of SBS (SB3, which nominally contained 3% SBS) through intermediate levels (SB4 at 4% and SB5 at 5%) up to higher levels (SB6 at 6% and SB7 at 7.5%). Asphalt binder grades included three grades based on SBS, one crumb rubber grade, one EVA-modified grade and one grade based on ethyl methacrylate (EMA), a polymer type that has been confirmed by the supplier as no longer being manufactured.

Since its publication at the end of 1992, APRG Report No.7, Part 4 has been superseded by several updates, culminating in the current Specification framework for polymer modified binders and multigrade bitumens, which is published by Austroads (2006a) as Technical Report AP-T41. This document focuses on bituminous binder applications where standard bitumens, i.e. those manufactured to Australian Standard AS2008 (Standards Australia 1997), may not provide adequate performance in service.

The only new polymer modifier to be incorporated into the Austroads PMB specification since national specifications were first published is PBD. This polymer modifier was included in the 1997 edition of the Austroads specification (Austroads 1997) with the introduction of the S35E sealing grade and the A25E asphalt grade.

Specified properties

The core properties specified in the Austroads specification are widely recognised and are:

- Viscosity at 165°C,
- Torsional recovery at 25°C, and
- Softening point.

However, these properties do not provide an indication of performance other than in a broad empirical way. In general the specifications have been derived from characterisations of PMBs available at the time the specification was drafted and are based around general field observations of products that were known to perform well in service.

Although the specification is intended to be framed around the results of nationally co-ordinated field trials and laboratory studies, in reality many of the specified properties have never been validated against performance. This is particularly the case for sprayed seal binders, where laboratory simulation of performance is problematic and well-controlled field trials have been few and far between.

Consequently, many of the specified properties have come and gone as the Austroads PMB specification has evolved due in part to there being insufficient evidence of a demonstrable link with field performance, for example:

- Ductility at 4°C,
- Aggregate Retention,
- Toughness at 4°C and 1m (by Force Ductilometer),
- Elastic Recovery at 45°C, and
- Consistency at 45°C.

The current specification also includes properties that are only required to be tested on an infrequent basis, or are only required to be reported but are not specified due to their ‘experimental’ status, including:

- Consistency at 60°C
- Stiffness at 15°C or 25°C
- Elastic Recovery at 15°C and 60°C (some grades)
- Toughness at 4°C and 100mm (by ARRB Extensiometer)

The problem with this disconnection between specified properties and validated field performance is that compliance to the specification can not be relied upon to provide assurance of performance.
Binder selection to prevent crack reflection

The Austroads specification framework (Austroads 2006a), along with its companion document, the Austroads Guide to the selection and use of polymer modified binders and multigrade bitumens (Austroads 2006b), provide guidance on the selection of treatments for both sealing and asphalt applications. These guides generally recommend the use of more highly modified binders for the more demanding pavement and traffic conditions. This can be shown in the recommendations for strain alleviating membrane (SAM) treatments, which are recommended for minimising the risk of reflection cracking on either existing cracked surfaces, or where there is potential for cracking.

Polymer modified binders recommended in the Austroads specification framework and the Austroads guide for application in SAM seals are shown in Table 1.

The degree of polymer modification for these PMB grades increases across the range from S10E and S35E to S20E and S25E, with the latter being the most modified (Austroads 2003). The softening point of a binder can be used as a very general indicator of the level of polymer modification of a PMB with typical values ranging from around 50 - 55°C for the S10E and S35E grades to 65 - 100°C for S20E and up to 80 - 105°C for the S25E grade.

<table>
<thead>
<tr>
<th>Rate of crack movement</th>
<th>Slow (environmental)</th>
<th>Rapid (traffic induced movement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crack severity</td>
<td>All</td>
<td>Low (&lt;2mm)</td>
</tr>
<tr>
<td>Suggested PMB grades</td>
<td>S10E, S35E</td>
<td>S20E</td>
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</tbody>
</table>
The need for a new binder

Some high profile seal failures have drawn attention to the difficulties associated with spraying highly-modified SBS-based PMBs (Neaylon & Busittil 2007). Although not widespread, the occasional stripped seal has highlighted the need for close attention to construction practice when sealing with binders such as the S20E grade. For similar reasons, it is most unlikely that the more highly modified S25E grade would be considered for use as a SAM seal binder (it is more commonly applied in strain alleviating membrane interlayer (SAMI) treatments).

The cause of stripping in the relatively early life of SAM seals constructed with S20E binder has been attributed to the highly viscous and cohesive nature of this grade of binder as it cools prior to the application of sealing aggregate. Unless application is undertaken using best practice, including the use of clean precoated aggregate, spraying only in warm to hot conditions, applying stone immediately after spraying the binder and rolling close behind the sprayer, then the integrity of the seal may not be guaranteed. In some cases it has been observed that the S20E binder supplied may have been more highly modified than expected (Neaylon & Busittil 2007) resulting in an even more critical need to observe best practice during construction.

In 2007 the need for a new binder for SAM seal applications was recognised and development commenced in 2008. The objectives of the development program were to formulate a binder that would maximise the level of resistance to reflection cracking through a seal whilst also maximising the ease of use and aggregate adhesion and retention properties.
The laboratory measurement of resistance to crack reflection

The development objectives outlined above presented a considerable challenge in terms of understanding the relative performance of sprayed seal binders, particularly with respect to the assessment of crack reflection through a seal. Whereas asphalt can be assessed in a laboratory using recognised performance-related tests such as wheel tracking and fatigue, there are no well-recognised tests for the laboratory assessment of sprayed seal performance. In the absence of such a test, previous assessments of the ability of binders to restrict the reflection of cracks through a seal have been undertaken as road trials. This is an expensive exercise and can take several years. Consequently, a major technical milestone in the binder development program was the identification of a suitable laboratory test to assess the relative crack reflection performance of different binders.

Wilson et al. (2009) has reported on the development of such a test. The test provides a convenient and relatively quick means of determining the comparative performance of bituminous binders in resisting the reflection of cracks through a seal.

The new binder test utilises the Australian Road Research Board (ARRB) Elastometer in Extensiometer mode to measure the force required to stretch a sample of binder relative to the distance stretched. Earlier work by Tredrea (2003) using a similar test procedure showed a relationship between the forces observed and the asphalt fatigue performances of several binders. Wilson et al. (2009) used the asphalt fatigue test to rank performance in controlling crack reflection through a sprayed seal based on observations by ARRB that the crack reflection performance of different binders can be ranked by using their relative fatigue lives in a single asphalt mix.

**ARRB Extensiometer**

In the test a simple ratio is determined (the Force Ratio). Plots of asphalt fatigue life (cycles) versus the Force Ratio at both 10°C and 4°C gave regression coefficients of 0.91 and 0.90 respectively, suggesting a very good correlation across a variety of binders ranging from normal bitumens through to PBD-modified binders and highly modified SBS-based PMBs.

The Force Ratio was used to assess a range of prospective formulations in a much quicker timeframe (~ 2 hours per test) than could be achieved with asphalt fatigue testing (two weeks or more per test, depending on the binder type) or field trials, which would take several years and significant cost.
The laboratory measurement of binder adhesion

An important objective of the binder development program was to ensure ease of use and that aggregate adhesion and retention properties were maximised. In setting this objective, it was decided to benchmark these properties against OLEXOBIT SAM, a PBD-modified S35E sprayed seal grade PMB that is well known for its ease of use and excellent adhesive properties based on field observations over more than a decade of use across Australia (Dack 2008).

Conventional binder adhesion tests, such as the Vialit Plate test, have been found to give results that are contrary to field experience (Maccarrone et al. 1997). Therefore, development of a binder adhesion test that gives the same order of performance as seen in the field has been an ongoing part of the binder development program. Initial development has focussed on combining aspects of various established adhesion tests, such as the Shell Mini Fretting test (used to assess adhesion of stones to emulsion sprayed seals in Europe), the Wet Track Abrasion test (used to assess the long-term stone retention performance of bituminous slurry seals) and the Vialit Plate test (used to assess adhesion of hot binders).

Initial adhesion test results have given the same order of performance as observed in the field, i.e. Class 170 > S35E > S20E, however further work is being conducted to improve the repeatability of the test.
Properties and performance of the new sprayed seal binder

The outcome of the two year development program is a new sprayed seal binder, called OLEXOBIT MAX. This binder has been developed based on laboratory assessment of its properties compared to existing binders in common use. The final formulation was chosen to provide excellent resistance to reflection cracking whilst ensuring superior early life adhesion and excellent long-term aggregate retention. Due to the unique polymer modification used in OLEXOBIT MAX, it is able to be successfully applied over a range of weather conditions as low as 15°C. The binder also has excellent storage and travel stability.

It is important to note that the new binder was not designed to meet an existing specification, as to do so would not ensure that its performance attributes could be maximised.

**Recommended applications**

OLEXOBIT MAX is recommended for application in SAM seals under the following conditions:

- High cracking severity where there are some crack widths of >2mm and slow to rapid rate of crack movement.
- Where there are frequent surfacing defects, such as patching,
- Under heavy traffic loading,
- On steep grades and tight curves, and
- At intersections, T-junctions and heavy traffic entrances involving severe degrees of braking, acceleration or turning motions.

Typical test results are given in Table 2 and operational guidelines in Table 3.

---

**TABLE 2**

<table>
<thead>
<tr>
<th>Property</th>
<th>OLEXOBIT MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 165°C, Pa.s</td>
<td>0.50</td>
</tr>
<tr>
<td>Torsional Recovery at 25°C, %</td>
<td>47</td>
</tr>
<tr>
<td>Softening Point, °C</td>
<td>58</td>
</tr>
<tr>
<td>Consistency at 60°C (Mould B), Pa.s</td>
<td>850</td>
</tr>
<tr>
<td>Stiffness at 15°C, kPa</td>
<td>135</td>
</tr>
</tbody>
</table>

**TABLE 3**

<table>
<thead>
<tr>
<th>Recommended spray temperature</th>
<th>185 – 190°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMB factor</td>
<td>HSS 1.1</td>
</tr>
<tr>
<td></td>
<td>SAM 1.2</td>
</tr>
<tr>
<td>Cutting rates</td>
<td></td>
</tr>
<tr>
<td>20 – 25°C</td>
<td>5 – 7 parts</td>
</tr>
<tr>
<td>26 – 32°C</td>
<td>3 – 5 parts</td>
</tr>
<tr>
<td>33 – 38°C</td>
<td>2 – 3 parts</td>
</tr>
<tr>
<td>&gt;38°C</td>
<td>0 – 2 parts</td>
</tr>
</tbody>
</table>

*Where large cracks are present and crack movement is >0.5mm, a PMB alone will not provide a long-term solution and should be used in conjunction with a geotextile.*
Field assessments

Although in the early stages of field assessment, work conducted to date with OLEXOBIT MAX has confirmed its ease of use, presenting none of the problems commonly associated with alternative SAM seal binders.

An initial trial on Swanbank Road in Queensland has been conducted by the Queensland Department of Transport and Main Roads (QDTMR). The trial consisted of a double/double 14/7mm holding treatment over a pavement exhibiting severe and extensive cracking and surface defects. The trial involved construction with both traditional S20E grade binder and OLEXOBIT MAX to allow comparison of the two binders. Summary details of the trial are shown in Table 4.

<table>
<thead>
<tr>
<th>Trial date</th>
<th>11th and 12th November 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial location</td>
<td>Swanbank Road, Swanbank, Queensland</td>
</tr>
<tr>
<td>Contractor</td>
<td>Roadtek</td>
</tr>
<tr>
<td>Traffic (AADT)</td>
<td>640 – 730 v/e (52% CV / 25% LHV)</td>
</tr>
<tr>
<td>Surface condition</td>
<td>Crocodile cracking, delamination, patching, potholes, general extensive cracking</td>
</tr>
<tr>
<td>Pavement temperature</td>
<td>37 – 52°C</td>
</tr>
<tr>
<td>Seal design</td>
<td>Double/double 14mm/7mm</td>
</tr>
<tr>
<td>Aggregate source</td>
<td>Boral Ormeau Quarry</td>
</tr>
<tr>
<td>Aggregate precoat</td>
<td>Precoat APT2</td>
</tr>
<tr>
<td>Aggregate spread rate</td>
<td>14mm at 100 m²/m³ 7mm at 240 m²/m³</td>
</tr>
<tr>
<td>PMB factor</td>
<td>1.2</td>
</tr>
<tr>
<td>Basic binder rate</td>
<td>First coat: 1.08 L/m²  Second coat: 0.63 L/m²</td>
</tr>
<tr>
<td>Modified basic binder rate</td>
<td>First coat: 1.3 L/m²  Second coat: 0.8 L/m²</td>
</tr>
<tr>
<td>Binder design application rate</td>
<td>First coat: 1.7 L/m²  Second coat: 0.8 L/m²</td>
</tr>
<tr>
<td>Actual binder application rate</td>
<td>First coat: 1.8 L/m²  Second coat: 0.6 L/m²</td>
</tr>
<tr>
<td>Binder temperature</td>
<td>180 – 190°C</td>
</tr>
<tr>
<td>Cutter</td>
<td>None</td>
</tr>
<tr>
<td>Adhesion agent in binder</td>
<td>0.6% AggBind Exp 90</td>
</tr>
</tbody>
</table>

Several inspections of the trial site following construction have confirmed the excellent stone retention properties of OLEXOBIT MAX, even under the fast-moving heavy traffic experienced on this site. At the most recent QDTMR inspection in February 2010 the seal was observed to be performing very well and better than expected given the severe conditions with no sign of reflection cracking.

Further product trials and demonstrations are being undertaken and will be reported more fully in the future.
Swanbank Road, Queensland

Road condition prior to trial

Application of OLEXOBIT® MAX

After 1 week

After 3 months
Summary and conclusions

A new sprayed seal polymer modified binder has been developed to provide excellent resistance to crack reflection whilst also providing ease of use and very good stone adhesion and retention properties. Currently specified PMB properties do not provide direct guidance on these binder characteristics. Consequently, development of the new binder required the development of a laboratory test to rank the relative performance of different bituminous binders to resist the reflection of cracks through a sprayed seal. Work is also ongoing on the development of an adhesion test that will provide the same order of performance as is observed in the field with initial work showing promise. Early sprayed seal trials have confirmed the performance characteristics of the new binder.

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Author biography

Stuart Dack is the Bitumen Marketing & Product Development Manager, previously for BP Australia Pty Ltd and now for Puma Energy (Australia) Pty Ltd. He has been involved in the development, production, application and marketing of bituminous binders for road construction and maintenance in Australia and Europe for over 20 years.

In this time he has been involved in the introduction to Australia of bitumen emulsion, polymer modified binder and bituminous slurry surfacing technologies.

Prior to his employment in the bitumen industry, Stuart worked on petroleum product development, brown coal research, and research and development of commercial bulk explosives for the mining industry.

He has several publications and patents arising from this research work. Stuart holds a Masters in Applied Chemistry and a MBA in Technology Management.
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