PERFORMING SEALS – FACTORS AFFECTING SUSTAINABLE SPRAYED SEALING PRACTICE

Stuart Dack, Bitumen Marketing & Product Development Manager, BP Australia Pty Ltd
Victoria, Australia
Adrian Grbac, Bitumen National Sales Manager, BP Australia Pty Ltd, Queensland, Australia

Abstract
Sprayed seals are the predominant pavement surfacing across the Australian road network, covering over 80% of the all-weather roads. Typically, a simple sprayed seal may vary in life from 7 to 15 years. However, considerably different lifetimes may eventuate depending on a range of causes, including the choice of treatment, quality of materials and operational aspects of construction, amongst other influencing factors. From a sustainability and budgetary viewpoint, a difference in age of several years may have a significant impact on the consumption of scarce high quality sealing aggregate and bituminous binder and on the whole-of-life greenhouse gas emissions attributable to the seal. This paper will discuss the important factors affecting the lifetime of a sprayed seal and their impact on sustainability and asset management budgets from a qualitative viewpoint.

Key Words: Sustainability, sprayed seals, road construction, road maintenance, pavement management, asset management, bituminous binder

Introduction

Sustainability and climate change are the catch phrases of the 2000's. But what exactly is meant by sustainability?

In 1987, The World Commission on Environment and Development provided the most commonly used definition of sustainable development describing it as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN 1987).

Current sprayed sealing practice consumes resources such as good quality sealing aggregate and bituminous binders and therefore can not be considered sustainable. However, every effort should be made to make the most of these limited resources, to make them last as long as possible, and to look for ways of reusing the materials as much as possible when the end of life is reached.

Of course, sustainability is not just about raw material use. A more holistic view of sustainability also includes the impact on local and global ecosystems, particularly with respect to emissions that may contribute to global warming.

The Intergovernmental Panel on Climate Change (IPCC) has reported that the global average surface temperature has increased by 0.7 ± 0.2°C over the last 100 years (Solomon, et al. 2007).

Although this observation is important, changes in extreme weather conditions may have greater impacts. The last three decades have seen the following changes associated with a warming planet (Solomon, et al. 2007):

- more frequent heat waves, hot days and hot nights
- less frequent cold nights and frosts
- more frequent very heavy rain events
- more frequent droughts.

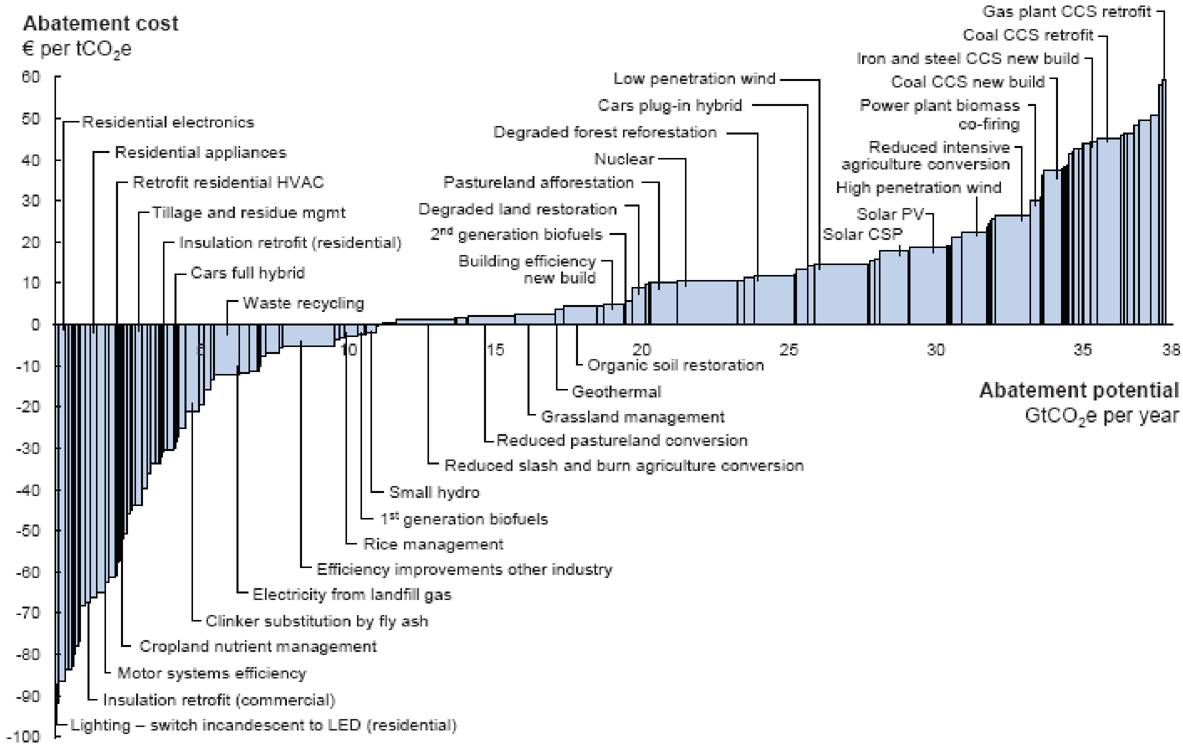
These changes will continue into the future with the CSIRO and Australian Bureau of Meteorology (2007) predicting that annual average temperatures across Australia will increase by 1 – 5°C by 2070 accompanied by changes in temperature extremes, with fewer frosts and substantially more days over 35ºC.

Global warming contributions are usually considered in terms of greenhouse gas (GHG) emissions. To understand the GHG emissions relating to any particular activity, consideration must be given to both the direct emissions (e.g. due to the burning of diesel fuel in a process) and the embodied energy within the materials used (i.e. the energy used to produce and deliver the raw materials required for a process), often expressed as its equivalent GHG contribution, or CO_2-e.

For sprayed seals and more generally in road construction and maintenance, most of the embodied energy is held in the pavement itself, rather than in the seal. So, preserving a road pavement by maintaining its waterproofness, for example, may be a significant contributor to the reduction of future GHG emissions by lessening the need for future pavement rehabilitation or reconstruction.

Austroads (2004) have identified the direct impacts of climate change on road infrastructure, with those most relevant to the integrity of sprayed seals being:

Figure 1 McKinsey Global GHG cost curve



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.0

- pavement deterioration due to altered moisture balances arising from rainfall changes
- accelerated ageing and embrittlement of bituminous binders due to increased temperatures – leading to surface cracking and increased stone loss
- more severe rain events.

Options to improve the sustainability of sprayed sealing and to reduce contributions to global warming include:

- resource sustainability – making the most of finite resources, such as good quality sealing aggregate and bitumen
- climate change – reducing GHG emissions by:
  - using processes that require less energy
  - using materials with lower embodied energies
- coping with the effects of increased temperatures.

McKinsey & Company (2009) has looked at options available for delivering GHG reductions (Figure 1).

In their greenhouse abatement cost curve they provide a range of options for reducing GHG emissions, some requiring considerable financial investment, some that are cost neutral, and some that also deliver economic benefits. The latter are the 'low-lying fruit' that should be considered for immediate implementation, particularly as they have a positive financial outcome.

In the context of sprayed sealing practice and from a binder supplier's viewpoint, the following sections identify some of the 'low-lying-fruit'. These are low or cost neutral, pragmatic and readily implementable opportunities to improve the sustainability of sprayed sealing practice and to reduce overall contributions to global warming, principally by ensuring the best seal life outcomes.

Readers with an interest in extending the life of sprayed seals and consequently reducing their environmental impact are encouraged to explore the references provided for further details of the issues raised.

Consequences of Reduced Seal Life

Sprayed seals cover 30% of the Australian road network and over 80% of the all-weather roads protecting road pavements valued in 1999 at over $70,000 million (Oliver 1999).

In 2006 VicRoads convened a forum to develop an understanding of the factors contributing to reductions in seal life (Midgley & Mangan 2007) and concluded that the following were significant:

- aggregate loss outside and between wheelpaths
- poor maintenance patching reflecting through the new seal
- unsatisfactory design of the treatment
- weather-related issues during sealing
- undesirable timing of the treatment.

The VicRoads study found that some roads were needing to be resealed 2 to 3 years ahead of their expected seal lives of 7 years (for 7mm seals) and 12 years (for 14mm seals). Such a shortfall in seal life represents an increase in GHG emissions associated with the sprayed sealing process and the materials used of between 20 and 75%. Reduced sprayed seal lives also lead to a greater consumption rate of materials, such as sealing aggregate and bitumen.

Programming

It is clear from our experience that work is often performed in marginal weather conditions that are detrimental to the achievement of a good seal. This is often an outcome of the need to spend budget allocations prior to the end of a financial year. Pavement preparation, including patching work, is also often scheduled too close to application of the seal. These wholly controllable factors can significantly affect the lifetime of a seal with the following potential consequences:

- early life stripping due to poor adhesion of sealing aggregates
- bleeding of soft binder through areas where patching or crack sealing has been undertaken and cutter or flux has been trapped.

Interventions in these cases can be expensive and a significant amount of aggregate and binder may be wasted.

Every effort should be taken to schedule sprayed sealing during the dryer and warmer months. This is even more important when modified binders are used. If work must be scheduled during periods when weather is likely to be marginal, then the choice of binder is critical – don't specify binders that require perfect conditions to get the sealing aggregate to stick!

Underlying patches must be given sufficient time to cure prior to sealing and this requirement must be built into contracts. Depending on the maintenance treatment, periods of up to 12 months between maintenance and sealing may be required to ensure the pavement preparation work has sufficient integrity prior to sealing.

Budgeting and accounting practices that drive inappropriate program timing should be reviewed.

Pavement Preparation

VicRoads (Midgley & Mangan 2007) found that the condition of the underlying pavement influenced the final seal life due to the following factors:

- insufficient dry-back of freshly prepared unbound granular pavements, allowing embedment of the sealing aggregate, leading to flushing
- poor levelling practice resulting in boney or hungry surface sections that absorb binder, leading to isolated stripping
- inadequate correction of poor surface areas resulting in soft patches and subsequent embedment of the sealing aggregate

Midgley (2008) documented the steps required to provide a suitable quality of unbound granular pavement. A high quality, long-life sprayed seal is dependent upon the quality of construction and the integrity of the underlying pavement structure. A seal will have reduced life if the pavement is weakened by inadequate design, poor quality materials, poor construction techniques or

poor maintenance practices (Midgley 2008). Pavement surface preparation during construction also contributes to the final seal lifetime. Slurrying the surface to provide smoothness may prevent adequate penetration of the prime and result in delamination of the subsequent seal.
Priming of a pavement must be undertaken with sufficient lead time to ensure curing can occur prior to sealing, otherwise cutter will be trapped under the seal and contribute to flushing. This problem may not be immediately apparent, but may manifest itself some time in the future on a particularly hot day, or when traffic volumes increase, for example due to holiday traffic. Priming in cooler weather may restrict penetration and result in excess primer and cutter oil on the pavement surface prior to sealing (Fenton 2008).

Treatment Selection and Design

Apart from issues relating to the timing of work, budgetary influences and procurement processes also affect the choice of treatment. Unfortunately, there are many examples on local roads where inappropriate choice of treatment has resulted in less than desirable service (Pashula 2003).
Choice of treatment should take into account factors that influence whole-of-life GHG emissions and utilisation of non-renewable resources.
Where long-term ageing of the binder is the likely predominant distress mode, the most durable binder will deliver the most benefits. If short-term distress is envisaged, for example due to the action of heavy vehicles at rural intersections, then seal design and binder choice should consider options more capable of withstanding those conditions. Normal Class 170 bitumen will not be adequate in situations where extreme stresses are placed on the seal, particularly in an increasingly warmer climate and with more powerful and heavily laden vehicles. In such circumstances a PMB is appropriate.
Design of the seal is critical. If the design traffic count inputs are inaccurate, then the design binder application rate may be either too high or too low with potential short and long term consequences. Incorrect average least dimension (ALD) for the sealing aggregate may bring the same detrimental outcomes. Poor prediction of traffic demand increases may also result in reduced service life, particularly as a consequence of the introduction of Higher Mass Limits (Savage 2007).
The consequences of poor design are manyfold. Too much binder will obviously increase the risk of bleeding and flushing, with subsequent loss of texture and skid resistance. Binder application rates that are too low can be even more detrimental resulting in an increased susceptibility to early stone loss and reduced binder life due to more rapid oxidative hardening of the binder.

Construction Practice

Several studies of sprayed seal performance have identified construction practice as the most frequent cause of premature seal failure (Tredrea 1995).
There are many factors to be considered during construction that will influence seal life, some of which are highlighted here:

- dirty or wet sealing aggregate, which will inhibit adhesion to the binder
- over-application of precoat, which will inhibit adhesion to the binder, particularly if the precoat is still wet
- inappropriate or non use of adhesion agents, leading to poor adhesion of sealing aggregate or fluxing of the binder
- ALD of sealing aggregate not as used in design, leading to either stripping or flushing
- incorrect binder delivered to the job, resulting in stripping or flushing
- incorrect cutter rate (too little or too much), leading to stripping or flushing
- binder temperature too low, resulting in 'tram-lining' and eventual loss of stone in under-applied areas, or poor wetting of sealing aggregate causing stripping
- delayed aggregate spread, resulting in poor adhesion to cold binder
- inadequate rolling, which reduces the likelihood of proper stone orientation being achieved and reduces the build-up of good binder adhesion
- over-application of sealing aggregate, which may result in crushing of aggregate particles during rolling and will inhibit the achievement of proper

stone orientation, leading to stone loss.

In particular, the over-application of sealing aggregate should be avoided. This is not only because it inhibits the achievement of proper stone alignment, but also because it introduces a serious safety risk to drivers and leads to significant wastage of a valuable and finite resource.

Binder Choice

The life of a sprayed seal is highly dependent upon the characteristics of the chosen binder. A well designed and constructed sprayed seal will reach its end of life when it:

- no longer provides a waterproof surface to protect the underlying pavement due to cracking of the aged binder
- loses cover aggregate (fretting) due to the action of traffic
- loses texture.

Cracking of the binder and fretting are caused by oxidative hardening of the binder with age (Oliver & Boer 2008). Bitumens specified for use by many state road authorities in Australia include the requirement for durability, which is a measure of the intrinsic resistance of bitumen to thermal oxidation hardening (Oliver & Boer 2008). Consequently, high bitumen durability will be a significant leading factor in delivering longer life to a seal where cracking and fretting associated with long-term ageing of the binder is the predominant failure mechanism.

In many cases it has been found that the decision to reseal is based on the age of the seal rather than on its condition and may be premature, thus reducing the potential life of the seal (Oliver & Boer 2008). A delay in resealing based on a risk assessment approach has the potential to deliver several more years to the seal life.

Seal life may be determined by the ability of the binder to withstand the reflection of cracks from the underlying pavement, or the effects of high traffic stresses. In these situations, it is necessary to use modified binders. Austroads (2006a & Austroads 2006b) provides guidance on the selection and use of modified binders.

Where polymer modified binders are specified to cope with severe service conditions, there is a need to balance the requirement for long-term performance with the risk of short-term seal failure.

Binders modified with styrene-butadiene-styrene (SBS) polymers (such as S10E and S20E grades) can provide highly variable outcomes (Neaylon & Busuttil 2007). More so than other PMBs, these binders need perfect weather conditions, clean aggregate, and tight control of binder and stone application and rolling to avoid early life failure.

S35E grade binders manufactured from polybutadiene (PBD) polymer are generally accepted as having excellent initial adhesion and aggregate wetting properties. This allows their application in cooler conditions than would otherwise be appropriate for alternative PMBs.

Bitumen emulsions versus hot or cutback bitumen

The Austroads report on the Environmental Assessment of Emulsions (Austroads 2000) reports on a study of the environmental impact of the use of alternative forms of bituminous binders in sprayed sealing work, including the use of bitumen emulsions and foamed bitumen as a substitute to hot or cutback bitumen. As part of the project, the CSIRO were commissioned to investigate the use of bituminous binders, focusing on the potential atmospheric impacts of ozone depletion, air pollution and GHG emissions. In relation to 'carbon footprint', the findings of the study indicated that:

- the extra transport associated with a change from hot or cutback bitumen to bitumen emulsions involves an increase in GHG due to emissions created by transport fuel usage
- the contribution of any form of bituminous binder to air pollution or GHG emission is very small compared to other causes, such as energy production, transport, industrial processes, solvent use and agriculture.

The study determined that there is no clear overall benefit from the use of bitumen emulsions on the basis of GHG emissions and that particular job-specific circumstances are likely to play a big part in determining whether it is a benefit or not. There is also a cost impact in the use of bituminous emulsions. The Austroads report in fact concluded that emulsified forms of bitumen had a slightly higher embodied energy and therefore CO_2-e than hot and cutback bitumen.

This conclusion does not seem to be readily accepted by some. However, a quick sense check shows that the major proportion of energy use (and therefore GHG emissions) is associated with the manufacture and distribution of hot bitumen (i.e. crude production, refining and bitumen storage and handling). These processes occur whether the bitumen is used hot, with cutback, or as an emulsion. To use an emulsified form of bitumen there are additional energy uses associated with the emulsification process and additional transport energy use due to the diluted state of the bitumen. On the other hand, using emulsified forms of bitumen will slightly reduce the energy requirement between the point of manufacture of the bitumen emulsion and the point of use due to a slight reduction in the energy required to keep the material at a suitable handling and application temperature.

The Austroads report summarises these points in the statement, "The main primary differences occur due to the extra energy needed to make and transport emulsion (because of the presence of water) and the energy savings in the reduced heating requirements of emulsions. Where energy is based on fossil fuels use, this results in GHG increases or reductions."

Outlook for Oil Supply

There is much being said about the on-going availability of crude petroleum oil and bitumen. Although oil is a finite resource, the facts suggest that there will be no shortage in the medium term. The annual Statistical Review of World Energy (BP 2009) states that proved reserves are sufficient to meet current production for more than 42.0 years for oil, 60.4 years for gas and 122 years for coal (this is based on proved reserves, which are defined as those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known deposits under existing economic and operating conditions). The outlook for oil supply has been steady over the last 20 years at or around 40 years supply cover.

Coping with Higher Temperatures

Not only are traffic volumes, loads and tyre pressures increasing, but temperatures are expected to continue to rise. More importantly, the number of high temperature days is increasing and consequently, there will be an increase in seal distress due to high temperature. Such distress could include:

- loss of surface texture due to bleeding or flushing of the binder
- binder pick-up on tyres
- excessive movement of aggregate
- loss of aggregate.

Some specifying engineers have moved from using Class 170 bitumen in sprayed seals to the use of the more viscous Class 320. Some have suggested the introduction of a new intermediate grade, 'Class 240'. This move is apparently based on the perception that early seal life will be improved by using a more viscous bitumen. However, any benefit to the short-term performance of a seal due to the use of a more viscous grade of bitumen will be at the expense of overall seal life. This is because, in general, a more viscous bitumen has a lower durability and hence will suffer from age-related cracking earlier.

Trials by VicRoads and the Queensland Department of Transport and Main Roads suggest that there are no discernable benefits in the use of higher viscosity bitumen grades (private communications). If seal distress mechanisms relating to high temperatures are of concern – as will increasingly be the case into the future – then a more appropriate option is to use a PMB, such as the type typically used in high stress seal applications.

Further Information

Loss of experience and expertise as a consequence of the ageing workforce has been identified across a variety of industries and the sprayed sealing industry is no different. It is vitally important that skill levels be maintained and that best practice is effectively shared.

The issue of information sharing was identified at the 1st International Sprayed Sealing Conference held in Adelaide in 2008 and, as a consequence, the Australian Road Research Board (ARRB) has established a website specifically to share best practice in sprayed sealing. This can be found at http://www.arrb.org.au/sealing and provides links to a variety of manuals and guides published by the ARRB Group, Austroads,

the Australian Asphalt Pavement Association (AAPA) and the state road authorities. Holtrop (2008) provides an excellent overview of current sealing practice in Australia and the important factors to be considered in successfully selecting and designing a sprayed seal.
Specialist training courses and workshops are run by AAPA and are designed in consultation with industry, state road authorities and local government. Details of these courses can be found at http://www.aapa.asn.au.

Summary and Conclusions

1. Current sprayed sealing practice consumes valuable resources, such as good quality sealing aggregate and bitumen.
2. GHG emissions associated with sprayed sealing are increased by between 20% and 75% when sprayed seal life is reduced by 2 to 3 years.
3. Extending the life of sprayed seals will contribute to sustaining the availability of good quality aggregate and binder and to reducing GHG emissions.
4. Programming of sprayed seal work in periods of marginal weather may contribute to shorter seal life.
5. Budgeting and accounting practices that drive inappropriate program timing should be reviewed.
6. Careful attention to the preparation of underlying granular pavements, particularly to ensure adequate dry-back and surface integrity, will extend sprayed seal life.
7. Aspects of seal design, including the accuracy of traffic forecasts and aggregate ALD, will influence the life of a sprayed seal.
8. Construction practice is a frequent cause of premature seal failure and close attention is required to a variety of factors to ensure seal life is optimised.
9. Seal life is influenced by the durability of the binder and the ability of the binder to withstand crack reflection.
10. Where modified binders are required, careful binder selection and close control of construction practice are required to ensure satisfactory adhesion is achieved and to prevent short-term seal failure.
11. Bitumen emulsions do not provide a benefit in terms of GHG emissions as most of the embodied energy is attributable to the bitumen content.
12. It is expected that crude petroleum oil, and therefore bitumen, will be readily available into the medium term future with current supply cover of 42 years.
13. Increasing traffic loading and average temperatures and more frequent extremely hot days will require the increased use of modified binders to ensure seal lives are optimised.
14. Skill levels across the industry must be maintained to compensate for the loss of experience and expertise and a variety of resources have been identified for the learning and sharing of best practice.

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Author Biography

Stuart Dack is the Bitumen Marketing & Product Development Manager for BP 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 BP in Australia of bitumen emulsion, polymer modified binder and bituminous slurry surfacing technologies. Stuart sits on several industry technical committees for Standards Australia, Austroads and AAPA. Prior to his employment with BP, 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.
e-Mail: stuart.dack@bp.com
Address: 55 Toll Drive, Altona North VIC 3093

Adrian Grbac is the National Bitumen Sales Manager for BP Australia Pty Ltd. He has been involved in the oil industry for 21 years, 17 of which have been associated with the bitumen business in BP. Adrian is regularly called on to present to customer and industry groups on best practice in sprayed sealing. Adrian has held positions in auditing, credit management, management accounting, supply and logistics and sales within BP. Adrian holds a Bachelor of Business from Deakin University.
e-Mail: adrian.grbac@bp.com
Address: 701 Kingsford Smith Drive, Hamilton QLD 4007