CHANGES IN AUSTRALIAN PAVING-GRADE BITUMEN: ARE THEY REAL AND WHAT SHOULD AUSTRALIA DO ABOUT IT?

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ABSTRACT

There is a widely held perception that bitumen quality has reduced over the last thirty or so years. Bitumen suppliers certainly acknowledge that changes in the supply chain have occurred. However, they maintain that this is inconsequential to performance as the products remain within the requirements of the various paving-grade bitumen specifications. A review of existing information and literature pertaining to changes in Australian paving-grade bitumen supply and the performance of bituminous surfaces is presented. Changes in the crude oil sources and refineries for the manufacture of bitumen consumed in Australia is confirmed. There is also overwhelming evidence that the crude oil source and the refining impact on measurable bitumen properties, including the rheological composition, ageing profile and even the routinely measured specification parameters. Finally, there is significant evidence indicating changes in bitumen properties impact field performance of bituminous surfaces. Although not exhaustive, these examples form a science-based argument that, yes, variable field performance of bituminous surfaces has resulted from differences in bitumen properties, likely resulting from changes in oil sources and refining. The lack of confidence in field performance of different batches or supplies of the same grade of bitumen is concerning. This presents a challenge for the broader industry and must be addressed in a collaborative manner. A supplier-purchaser-client approach is essential and increased supply chain transparency would be beneficial for establishing a working level of trust across the industry.

INTRODUCTION

There is a widely held perception that bitumen quality has reduced over the last thirty or so years. Due to the absence of meaningful study and evidence, this perception can only be described as speculative or anecdotal. It follows that there is tension between bitumen suppliers in Australia, their customers, design consultants and the ultimate asset owners. Bitumen suppliers acknowledge that changes in the supply chain have occurred. However, they maintain that this is inconsequential to performance as the products remain within the requirements of the various paving-grade bitumen specifications (Preston 2005). In contrast, consumers, designers and asset owners report a decrease in bituminous surfacing life and increase in early-life performance issues.

The tension between bitumen suppliers and the industry is likely exacerbated by the lack of transparency regarding the source, supply and processing of bitumen in Australia. For example, the aggregate used to manufacture a particular asphalt is transparently and thoroughly understood. The quarry source is known and the geological history of the rock is documented. The aggregate is subject to petrographic and material property characterisation. Engineers often inspect quarries and working faces. Experienced engineers can detect detrimental changes in aggregate properties based on visual inspection of aggregate samples. In contrast, all a consumer generally knows about a particular batch of paving-grade bitumen is the grade and certified compliance to the relevant specification. It is expected that an increased understanding of the crude oil source and processing of bitumen supplies may reduce the tension and create an opportunity for trust between suppliers and the rest of industry.

The aim of this paper is to review existing information and literature pertaining to changes in Australian paving-grade bitumen supply and the impact on field performance of bituminous surfaces. The paper is structured by addressing the following questions:

- Have the sources of crude oil used to manufacture Australian bitumen changed?
- Have the refineries and refining processes of Australian bitumen changed?
- Have the properties of Australian bitumen changed as a result?
- Have changes in properties resulted in a decline in field performance?

Experience from New Zealand and South Africa is referred to where relevant. What the Australian bitumen and asphalt industry can, and should, do about the supply and quality of bitumen is also considered.

HAVE THE SOURCES OF CRUDE OIL CHANGED?

Crude oil sources used for the production of bitumen consumed in Australia are unclear. Bitumen suppliers resist disclosure of source information on the basis of intellectual property and commercial advantage. However, in 2005 it was acknowledged that crude oil for bitumen production in Australia was almost exclusively from the Middle East (Preston 2005b). Although Australia has its own crude oil reserves, these are not suitable for the production of paving-grade bitumen to Australian specifications.

Since 2005 significant changes have occurred in the Australian bitumen supply chain. In 2014 Shell Australia was sold to global bitumen trader Vitol (Shell 2014). Following the announcement of the closure of its Bulwer (QLD) refinery in 2014, BP Bitumen sold its Australian assets to fuel and energy trader Puma Energy (BP Bitumen 2015). Puma Energy also purchased the Caltex Australia bitumen business (Caltex 2013). With a transition in bitumen supply from ‘oil refiners’ to ‘energy traders’ the sources of crude oil are likely to become more diverse.

In 1997, New Zealand saw the introduction of independent bitumen importation. Since that time at least two companies have imported bitumen into New Zealand, manufactured from sources of crude oil that are significantly different from the traditional Middle Eastern sources (Vercoe 2005). Since the transfer of ownership of the main Australian bitumen suppliers (2013-2015) some have already investigated the suitability of alternate crude oil sources for imported bitumen supply. Further, some bitumen suppliers in Australia now import bitumen manufactured from US sources of crude oil. This trend towards more diverse sources of crude oil for manufacture is expected to continue in the future.

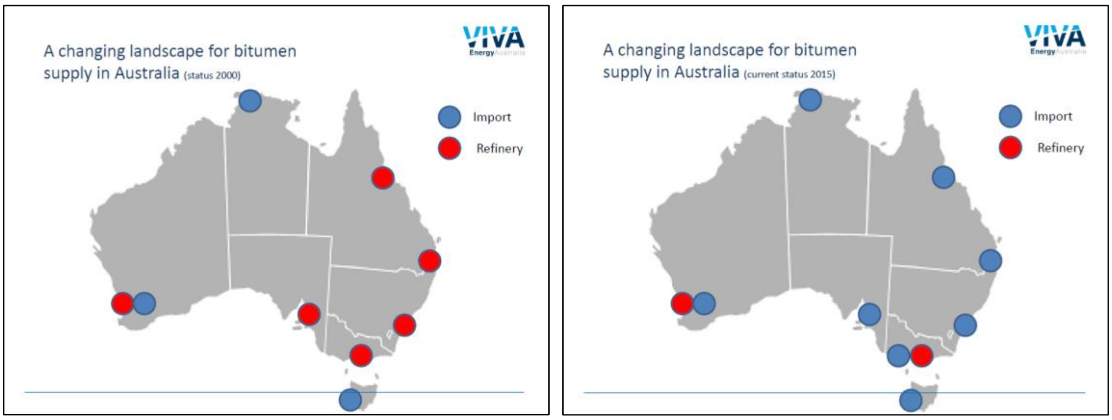
At the same time, global crude oil quality has declined. Average density is decreasing and sulphur content is increasing over time (ICCT 2011). Both trends are indicators of declining average crude oil quality. It stands to reason that if average crude oil quality is decreasing, then the quality of crude oil used to manufacture bitumen consumed in Australia is also likely to change.

In summary, yes, crude oil sources for the manufacture of bitumen consumed in Australia have changed. A constant supply from Middle Eastern crude oil has been replaced by more diverse and less transparent crude oil sources. New Zealand has already seen these changes take effect and the sale of Australian bitumen suppliers to global energy traders will likely see further increases in crude oil diversity in the future.

HAVE THE REFINERIES AND PROCESSES CHANGED?

During the 1940s Australian companies constructed a number of oil refineries for the manufacture of bitumen, petroleum fuel and lubricating oils (Neaylon 2013). As recently as 2011, additional investment was made in Australian bitumen manufacturing infrastructure. However, competition from new mega-refineries developed in Asia has put the older and relatively small Australian refineries at a significant disadvantage. A number of Australian bitumen refineries have subsequently closed or been reduced to bitumen importation and finishing facilities (Neaylon 2013).

The trend towards bitumen importation has been demonstrated by a number of reports. Bitumen production in Australia reduced from 579 ML in 2010-11 to just 150 ML in 2013-14, a 74% reduction in just three years (BREE 2014). Similar trends have been seen around the world. For example, South Africa imported just 152 tonnes of bitumen in 2012 compared to 20,100 tonnes in 2009 (Sabita 2014). A illustrative demonstration is by comparison of the number of bitumen-producing refineries (versus importation terminals and finishing facilities) in Australia in 2000 to 2015 (Figure 1). Many refineries have been converted to importation facilities and the Perth refinery is expected to cease bitumen production by 2017 (Preston 2015b).



(a) 2000 (b) 2015

Figure 1: Change in Australian bitumen refineries and import terminals (Preston 2015b)

With the transition of Australian bitumen supply from local production from imported oil to the importation of refined product, the refineries have clearly changed significantly. The mega-refineries that have rendered the Australian refineries unviable are larger and more efficient. The oil refining industry rejoices in terms like 'whitening the barrel' (Preston 2005b) and 'digging deeper into the barrel' (Vercoe 2005). The technological advances that allow these efficiencies include catalytic cracking, hydrocracking and propane de-asphalting (Speight 2004). While not new, the broad application of such technology has increased significantly in recent years as changing economic conditions has made investment in such technologies viable (Harvey 2015).

In the last century, technology advances in oil refining focused on achieving efficiency gains via increased yield from the middle-distillate portion of the crude oil. However, an increase in demand for high-value products, such as diesel, gasoline and lube oil, has occurred. This has refocused oil refining technologists on synthetically increasing the yield of these higher-value products, from within the heavy oil fractions (Rana et al. 2012). This directly impacts the composition of the residue available for the production of paving-grade bitumen and associated products.

As an example, between 1993 and 2013, the average diesel fuel yield from crude oil increased from 21% to 30% (43% rise). Over the same period the yield of bitumen reduced commensurately from 3.2% to 1.6% (50% drop) of the crude oil mass (EIA 2015). These changes reflect the ability for refineries to extract more of the high value products, at the cost of the lower-value products, such as bitumen.

One of the most significant changes in bitumen production in Australia is the trend to blends containing Propane Precipitated Asphalt (PPA). PPA is a by-product of lube oil production. The residue from lube oil production is treated with propane under pressure to precipitate out the larger molecules, which have a consistency similar to extremely hard bitumen. This is then blended with softer bitumen to extend it and harden it to grade (Oliver 2005). The question becomes whether a C170 or C320 bitumen produced from blending untreated (soft) product and a propane precipitated (hard) product has non-specification properties and an evolution of properties consistent with those of a traditional 'blown to grade' straight run bitumen.

In summary, yes, the refineries producing bitumen for Australian consumption have changed substantially. The predominantly Australian produced bitumen (from imported crude oil) has been almost completely replaced by imported bitumen manufactured mainly in the mega-refineries in Asia. These mega-refineries are more efficient at extracting more of the high-value products from the crude oil, such as diesel fuel. As a result, the residue available for bitumen production is reduced and of different composition.

HAVE THE PROPERTIES CHANGED AS A RESULT?

Changes in crude oil sources and refinery process are only significant if they impact on the properties of the paving-grade bitumen. It is well established that refinery processes change with crude oil source and that both oil source and processing impact bitumen chemical composition and properties (AI&E 2015). Australian bitumen suppliers also recognise the link between crude oil source, refinery processes and bitumen properties (Preston 2005b).

Through the SHRP program that led to the development of the Superpave asphalt specification in the USA, significant research into bitumen properties and testing was undertaken. This work led the USA to abandon empirically-based penetration grading of paving-grade bitumens for the Performance Grading (PG) approach. New Zealand is following the USA in this regard (Holleran et al. 2014). South Africa is also progressing the implementation of PG binder grading and performance based asphalt specification. The Superpave work included the collection, storage and characterisation of a broad range of 'standard' materials used over many years for research testing and the production of asphalt mixtures (Jones 1993). Comparison of the various properties of the bitumens of the same grade sourced from different suppliers across the USA provides overwhelming evidence that variation in crude oil source and processing impact measurable bitumen properties, despite comparable grading based on penetration.

In Australia, Oliver (2009) tested retained samples of C170 bitumen spanning 1966 to 2004. The rheological composition was measured by Iatroscan. The average Gaestel Index, an established indicator of bitumen rheology, decreased from around 0.5 to 0.2 over that period (Figure 2). In a related paper, Oliver (2005) demonstrated a reduction in the asphaltene content of the bitumen was associated with the increase use of PPA extended product. In similar work, Holleran & Holleran (2010) reported Gaestel Indices for various sources of compliant 60/70 penetration grade bitumens from NZ. Results ranged from 0.24 to 0.39. Complex modulus and Phase Angle, measured by DSR, were also significantly different for the four samples (Figure 3).

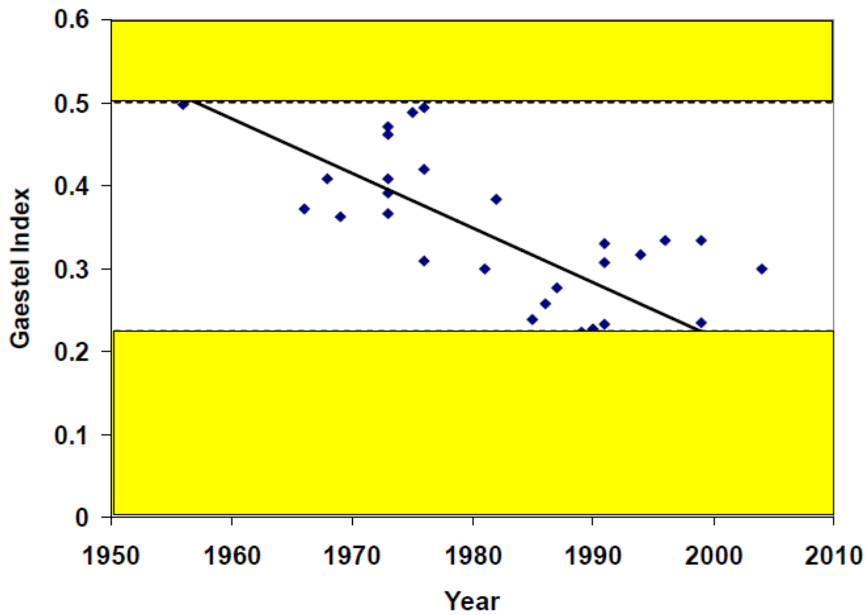
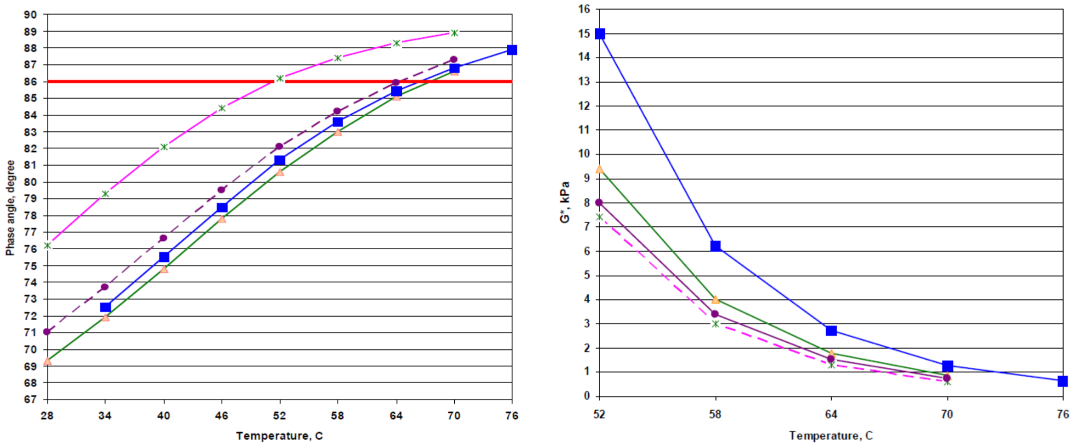


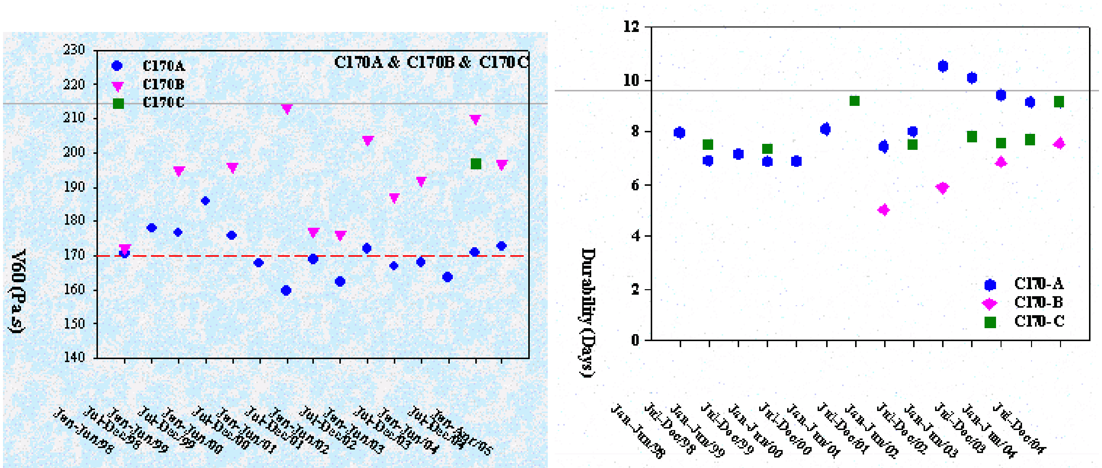
Figure 2: Australian C170 Gaestel Index with Time (Oliver 2009)



(a) (b)

Figure 3: Bitumen source impact on (a) Phase angle and (b) G* (Holleran & Holleran 2010)

In response to concerns from Queensland-based spray sealing practitioners regarding bitumen 'tenderness' in sealed surfaces, a review of C170 and C320 data was performed over time and between suppliers (Spies 2005). Significant changes in key properties were observed and consistent differences were observed in samples obtained from three independent suppliers (Figure 4).



(a) (b)

Figure 4: Various C170 source (a) viscosity and (b) durability (Spies 2005)

In a more recent study, fourteen samples of M1000 bitumen manufactured from two different crude oil blends produced in 2011 were retained and re-tested from time to time. Although all fourteen samples were compliant with the Australian specification, they were found to be significantly different at their time of production, as well as when re-tested in 2013, 2014 and 2015 (White 2015a). For example, the post-RTFO viscosity increased significantly and differently for the samples from the two crude oil sources (Figure 5).

In related work, properties measured by the DSR-based Multiple Stress Creep Recovery (MSCR) test of the USA were significantly different for the bitumen samples manufactured from the two feedstocks (White 2015a). Of specific note was the higher stress sensitivity of samples from Feedstock 2. Stress sensitivity of bitumen is a measure of the difference in cumulative strain between low (0.1 kPa) and high (3.2 kPa) cyclic shear loading. A high stress sensitivity indicates a high risk of inadequate bitumen performance during hot and or high-stress conditions. In similar work, C170 and three PMBs manufactured from the same imported bitumen shipment consistently showed very high stress sensitivity. Independently supplied C320 and M1000 samples showed 'normal' levels of stress sensitivity. This likely reflected the difference in stress sensitivity of the unmodified binder (White & Embleton 2015).

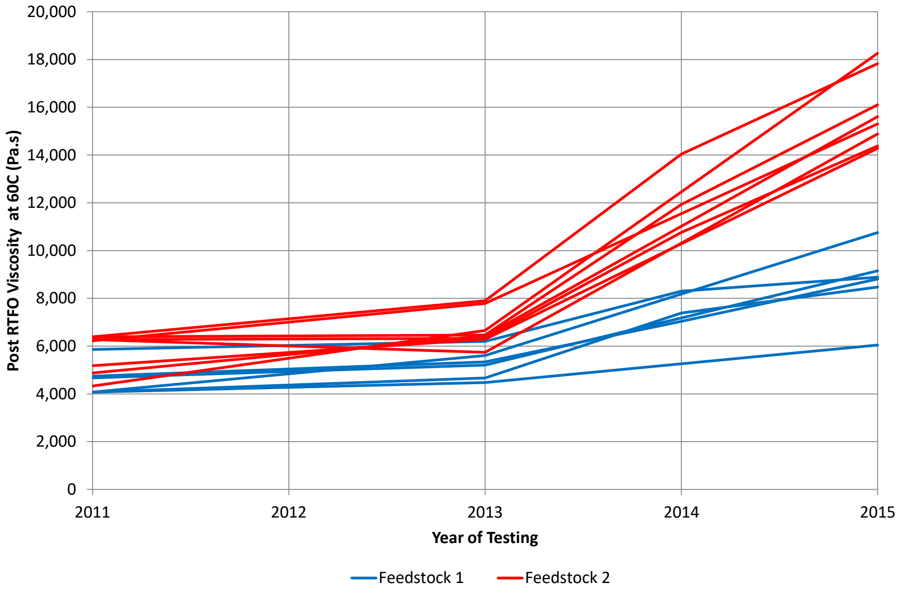


Figure 5: Australian M1000 post-RTFO viscosity change with storage time (White 2015a)

Austroads undertook a significant study on the impact of polymer segregation on asphalt performance (Austroads 2013). Three samples of compliant C170 were characterised with and without polymer modification. Elastic recovery, consistency, underlying viscosity and storage stability results were all substantially different for the SBS modified samples manufactured from the different C170 sources.

As part of the introduction of in-line blending certification of AR450, post-RTFO viscosity and penetration were traced over an eight month period. For this supply of AR450 binder, the ratio of these two properties varied from 27 to 43 (Preston 2015a). This is indicative of compositional variability within a constant local point of supply. Variability between suppliers would be expected to be similar or higher.

In summary, there is overwhelming evidence that the crude oil source and the refinery processes impact on measurable bitumen properties, including the rheological composition (expressed as the Gaestel Index), ageing profile in storage and even the routinely measured specification parameters, with and without polymer modification. As binder sources and refining processes change, as will the measured properties. Despite this, bitumen suppliers are able to modify imported bitumen sources to consistently achieve compliance with the various paving-grade bitumen specification parameters. However, non-specification parameters remain, by definition, uncontrolled.

HAVE THE CHANGES AFFECTED FIELD PERFORMANCE?

Changes in bitumen properties are only of concern if they impact the field performance of bituminous surfaces. Bitumen performance can be measured from observed field performance or from performance-based laboratory testing. Field performance is easily observed but isolating the impact of bitumen changes is challenging. In contrast, laboratory testing can easily isolate the impact of bitumen on a particular test result. However, this is only useful if the test method is recognised as a reliable indicator of field performance.

It has been suggested that the underlying properties required of good-performing bitumen for asphalt contradict those required for sound spray seal performance (Vercoe 2005). Australia, New Zealand and South Africa make significant use of spray seal treatments for pavements. This has created a significant challenge for bitumen specifiers and suppliers as a compromise is required between sprayed seal and asphalt binder suitability. The importation and isolation of two streams of bitumen, one with rheology suited to spray sealing and the other suited to asphalt applications, is logistically impractical. The practically necessary compromise between sealing-suitable and asphalt-suitable bitumen properties explains why Australia has experienced challenges that have not been frequently reported in the Middle East or the USA, where sprayed sealing is less common.

Fatigue, wheel tracking and modulus are all laboratory tests linked to asphalt performance in the field. Austoads (2013) compared nominally identical asphalt mixtures manufactured with three samples of compliant C170 bitumen and nominally identical PMB manufactured from the same three C170 samples. Wheel tracking of asphalt containing the three PMBs ranged from 4.2 mm to 7.1 mm. Flexural stiffness ranged from 8,100 to 10,700 while fatigue life ranged from 210,000 to just 58,000. For the asphalt containing C170, the flexural stiffness and fatigue life ranged from 8,600 to 10,800 and from 31,000 to 83,000 respectively.

White (2016a) investigated shear failures of airport asphalt containing M1000 binder. Two runways were surfaced with the same nominal mix design. One runway performed well while the other experienced significant asphalt tenderness resulting in numerous, isolated horizontal shear deformations in the surface. Bitumen and asphalt testing led to the conclusion that a change in crude oil source blend had introduced a binder that was less resistant to shear stress and more sensitive to high stress conditions. The change in crude oil source and associated difference in measurable bitumen properties was concluded to have resulted in the observed tenderness (White 2015b).

The work by Oliver (2009) showing the average reduction in Gaestel Index of Australian C170 bitumen over time was discussed above (Figure 2). Oliver (2009) also correlated the Gaestel Index of bitumen samples with observed field performance (Figure 6). The association between Gaestel Index, an indicator of bitumen rheological composition, and field performance was significant. Bitumens with high Gaestel Index often resulted in asphalt with colloidal instability and temperature sensitivity. Bitumens with low Gaestel Index frequently resulted in seal flushing. Between 0.22 and 0.40, field performance issues were not reported. This result is consistent with the suggestion made by Vercoe (2005) regarding the competing requirements of bitumens for sprayed sealing and asphalt performance.

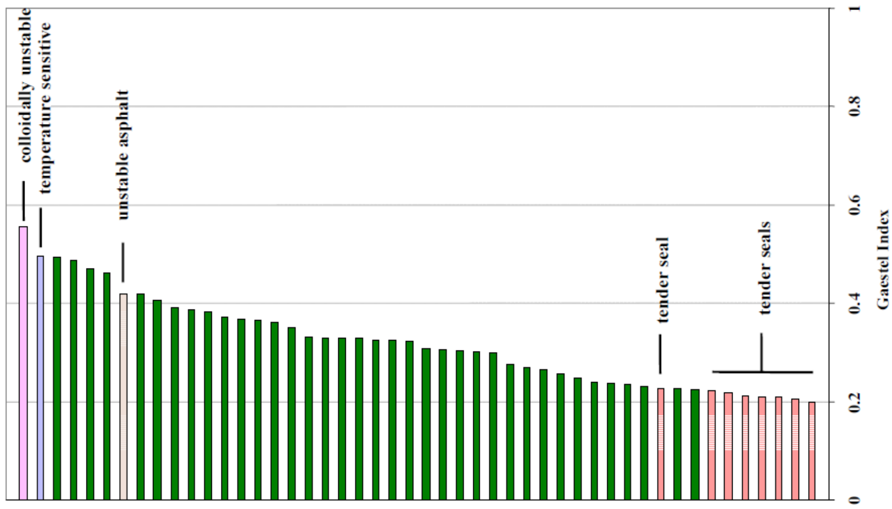
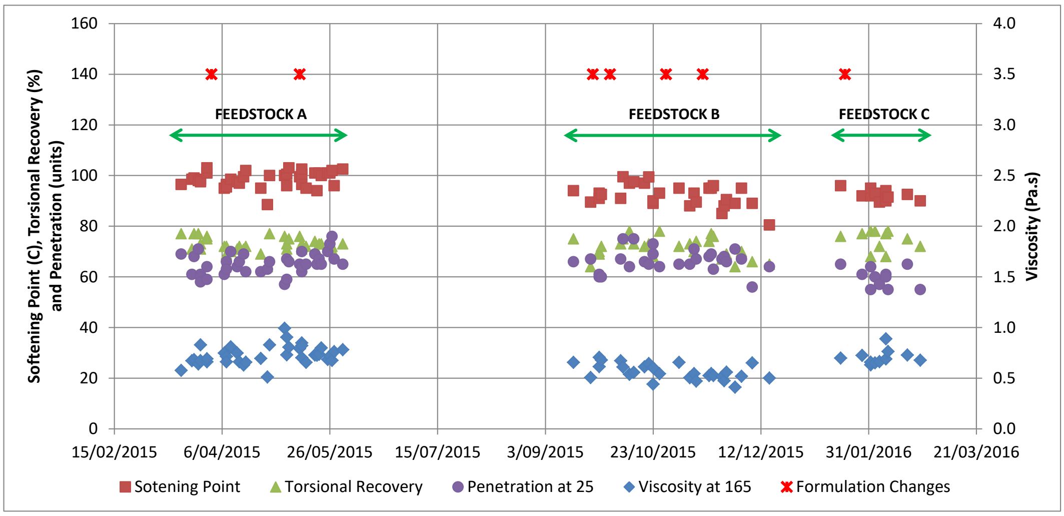
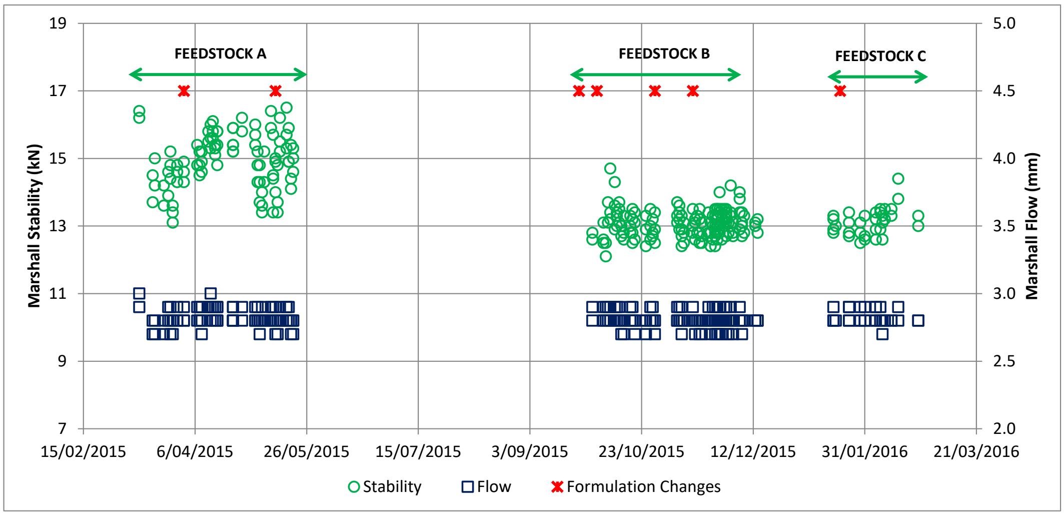


Figure 6: Australian C170 Gaestel Index correlation with Field Performance (Oliver 2009)

White (2016b) correlated the source of imported C170 bitumen (feedstock), A10E formulation adjustments, A10E properties, asphalt properties and field performance over twelve months. All asphalt was utilised to resurface major taxiways at an Australian international airport and all A10E and asphalt complied with the respective specifications. From Figure 7 it was concluded that feedstock changes were significant while formulation adjustments were not. It was also concluded that the feedstock changes resulted in significant changes in both PMB and asphalt production properties and that these changes were well correlated to the performance of the asphalt in the field. As the C170 source changed, the A10E softening point was reduced. The asphalt Marshall stability was subsequently reduced and the asphalt became more difficult to compact during construction, with an increase in shoving and rutting of the surface also reported.



(a) Bitumen properties



(b) Asphalt properties

Figure 7: Feedstock and Formulation impact on (a) PMB and (b) asphalt (White 2016b)

In summary, there is significant evidence indicative of changes in bitumen properties impacting field performance of bitumen. Seals with low Gaestel Indices have flushed and asphalt with high Gaestel Indices have been susceptible to stress and temperature. Asphalts produced from the same grade of binder, manufactured from different crude oil sources, showed significantly different resistance to shear stresses on runways and taxiways. In the laboratory, otherwise similar asphalt manufactured with different sources of C170 bitumen returned significantly different fatigue lives and rutting under wheel tracking. Although not exhaustive, these examples indicate that, yes, variable field performance of bitumen has resulted from differences in bitumen properties, likely resulting from changes in oil sources and refining.

WHAT CAN AND SHOULD WE DO ABOUT IT?

There is significant evidence that Australian bitumen crude oil sources and refining have changed. This has had a significant impact on the measurable properties of bitumen. Generally, the measurable changes in properties have been indicative of a decline in bitumen quality. In some cases, there are demonstrable links between the change or decline in bitumen quality and field performance of bituminous surfaces and/or performance-related laboratory testing of asphalt.

The reality is that bitumen is a by-product of oil refining for the production of more valuable commodities such as petroleum gas, petroleum fuel, diesel fuel and lubricating oil. It is the least modified version of the waste generated from crude oil refining. Minimisation of the ‘by-product’ for the maximisation of the high value products makes oil refineries around the world more efficient and competitive. As a result, advances in refining technology impact the bitumen yield and may impact the properties and performance of the resulting paving-grade bitumen.

So what can/should Australian paving-grade bitumen consumers (road authorities, port owners and airport corporations) do about this? A number of options exist, the main ones being:

- Do nothing and accept that every now and again, the bitumen quality will change or reduce.
- Amend our bitumen specifications to change the bitumen we import and/or the way we classify, grade and 'use' the bitumen we currently have available.
- Accept the current bitumens we have available, but modify them in new ways that better improve their engineering properties and field performance.
- Lobby oil refiners and bitumen suppliers to change the bitumen they produce and/or the sources they produce it from, in order to minimise future changes.
- Discontinue our use of asphalt and other bituminous products as a pavement construction and surfacing material in applications where the (changing) bitumen properties result in a high risk of unacceptable performance.

The 'do nothing' and 'discontinue use' options are unpalatable, uneconomical and do not represent an approach that is recommended for an advanced country like Australia. Lobbying suppliers for more consistent product is unrealistic. On a global scale, Australia is a very small consumer of bitumen at just 58,000 tonnes per annum (BREE 2014) from the estimated global demand of 110,000,000 tonnes per annum (TRM 2014). It is naive to expect the global industry to change its philosophy and reduce overall oil refining efficiency for a country that represents only 0.05% of global demand of one of its by-products.

That leaves the options to change the Australian bitumen specifications and/or better modify bitumens to improve their performance. Bitumen modification (by polymers, acids and other chemicals) is already routine in Australia (White & Embleton 2015). In high demand environments, such as ports and airports, modified bitumen is already the norm. Further improvement may be possible with new modifiers. The alternate approach is to re-classify or re-define the crude oil and bitumen sources that Australian suppliers import through adjustment of the Australian specifications. This may include the addition of new test methods (such as MSCR) to the current specifications or a substantial change in the way we grade and specify bitumen (such as following NZ and South Africa in adopting the PG approach from the USA).

Changing the long-established bitumen specification should not be taken lightly. The current bitumen specification (AS 2008) was updated in 2013. A further revision would take significant time and effort. Any change would also require compliance testing laboratories to purchase additional equipment and become accredited for additional test methods. Such changes are only justified if the resulting classification and grading system is likely to substantially reduce the risk of future field performance issues. This may include re-grading imported bitumen feedstocks to permit those problematic products to be used in low-demand circumstances. However, having 'high' and 'low' demand specification requirements for similarly classified materials implies logistical complexity that must also be addressed.

SUMMARY AND CONCLUSIONS

Anecdotal evidence over thirty years suggests that bitumen/oil sources and refining processes have changed. This has impacted Australian paving-grade bitumen properties and the resulting performance of some bituminous surfaces. Being high stress and high temperature environments, Australian airports are likely to be the first to notice changes in performance.

This paper has collated a number of documented Australian studies and various publications regarding bitumen sources, refining processes, the resulting properties and potential impacts on field performance of bituminous surfaces. There is general acknowledgment by suppliers that the sources and supply chains have changed. The impact on non-specification properties and field performance is less clear. However, significant evidentiary examples have been provided.

The lack of confidence in consistent and adequate field performance of different batches of bitumen, compliant to the same grade and specification, is of concern. This presents a challenge for the broader industry and must be addressed in a collaborative manner. A supplier-purchaser-client approach is essential and increased supply chain transparency is critical to establishing a working level of trust across the industry.

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