DEVELOPMENT OF A DEFORMATION RESISTANT ASPHALT FOR PORTS AND CONTAINER TERMINALS

Peer Reviewed

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ABSTRACT

Ports and container terminals present some of the greatest challenges in pavement engineering. These pavements have to withstand axle and point loadings exceeding 100 tonnes which is tenfold more than road pavements. Over the last fifteen years an attempt has been made to develop asphalt mixes based on performance testing to withstand the extremely high static and dynamic loads in hot climates experienced under straddle carriers, forklifts and containers. Because of the unusual conditions at container terminals, a different approach is applied to designing mixes and pavements, that while drawing on the best elements of asphalt engineering, extends beyond existing public road specifications.

Building on Austroads procedures, utilising the latest available binder technology and using first principles to optimise all components of an asphalt mix, a special port mix has been developed. This paper describes the journey to developing a highly rut resistant mix and the placement of this mix in a number of port and container terminals throughout Australia.

BACKGROUND

Ports and container terminals are notorious for having some of the most severe conditions that pavements can experience. All types of pavements, asphalt, concrete and segmental block pavers have been used to address these conditions with various degrees of success. Subgrades are frequently poor and can contain marine silts and clays, alluvial sands including organic matter or similar geology. Substructures have been built over decades if not centuries sometimes using cut-to-waste that has been refused at other locations. Pavement configurations also vary due to different engineering standards over time and the dynamics of the port area growth.

Loads in port and container terminals are usually an order of magnitude greater than those experienced on typical public roads and require a different design approach. The fundamental distress mode to control is rutting under slow moving often channelized movements of container handling vehicles like, reach stackers, large forklifts and straddle carriers.

Around 2001, Boral was approached by port operators to design an asphalt mix that would withstand port and container loading conditions while conforming to a specification for wheel tracking specifically prepared for this environment. An asphalt solution was considered appropriate due to expedience and cost effectiveness in these rehabilitation situations. There has been a commitment towards continuous improvement of Portmix™ ever since.

PORT & CONTAINER FACILITY LOADING

Loading in the container and port facilities is an order of magnitude different to typical highway traffic. Compared to the standard Austroads axle of 8 kN and 2 tonnes/wheel, container-handling vehicle masses are often close to 100 tonnes with individual wheels carrying around 10 tonnes/wheel. Loading can also be extremely channelized.

Wardle (Circa 2002) [(5)], Figure 1, shows the equivalent vertical compressive strains are deeper in the pavement under a heavier wheel load and it may be surmised that the confining pressures contribute to alleviating crack propagation in these environments. Larger rest/healing periods between loads that apply a deep seated kneading action might assist this phenomenon for both top-down and bottom-up cracking.

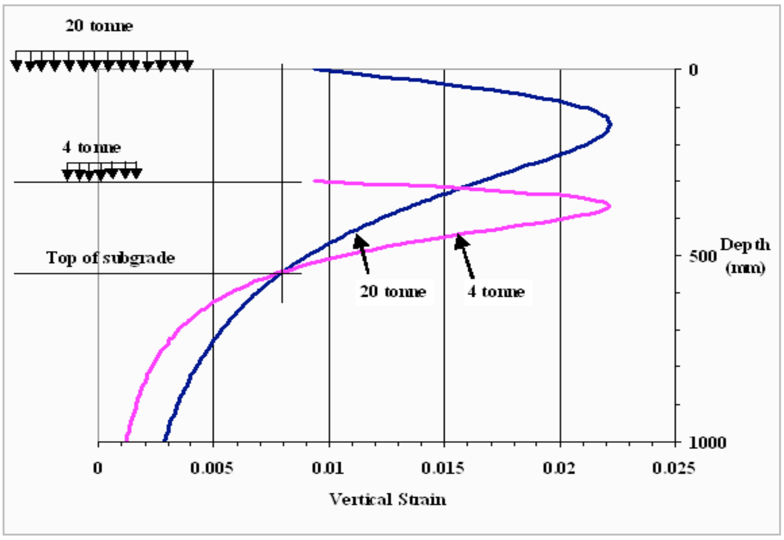

Figure 1: Vertical strain distribution for different loads (Wardle, Circa 2002) [(5)]

EXISTING CONDITIONS AND TYPICAL FAILURE MODES

Arguably, consequences to container facility operations are greatest when pavements fail prematurely by rutting while other failures like shrinkage cracking and ravelling are less prevalent, having little short term impact when they occur. Port pavement can also be damaged by shattering or indentation where the corner casts from containers impact on the surface and this is a significant concern for operators.

Pavement deformation affects the handling characteristics and safe operation of straddle carriers, cranes and other vehicles. In particular, driver health can be adversely affected by rut bumps that are amplified by the size, weight and related suspension characteristics of port vehicles, making back injuries a significant OH&S concern for port managers.

Corner cast damage results in deterioration of stacking areas and the ability to safely store containers especially when stacked in multiple layers. Re-positioning containers due to corner cast pavement damage is more challenging to accommodate especially with auto-straddle operations.

Transverse cracking can emerge due to reflective cracking from underlying bound layers but is unlikely to reduce the serviceability of the pavement. It might be opined that the high compressive stresses due to very high wheel loads have a part to play in retarding the propagation of these cracks to the surface because of the amplified kneading action on the mix. This is in contrast to observations with highway loading regimes where cracking is exacerbated by increasing load.

Ravelling when observed is generally a symptom of aged asphalt but can sometimes be a result of coarse aggregate mixes used in port pavement wearing courses.

The primary distress mode in areas initially rehabilitated with trial port mixes was rutting. These areas consisted of well defined grids line-marked for straddle carriers to load containers onto trucks. The highly channelized paths for straddle carriers defined by these grids (Figure 2) enable asphalt to be tested in controlled, extreme conditions. Another advantage in this area was that pavement consisted of a 75 mm asphalt layer over concrete base in very sound condition, making it very easy to identify if any observed deformation was within the asphalt.

Figure 2: Truck grid area where straddle carriers have highly channelized narrow lanes

Deformation exceeding 110 mm was measured in these truck grids as shown in Figures 3 and 4. Initial trials consisted of a variety of standard and modified asphalt mixes in separate grids.

Figure 3: Deep ruts in straddle carrier lanes

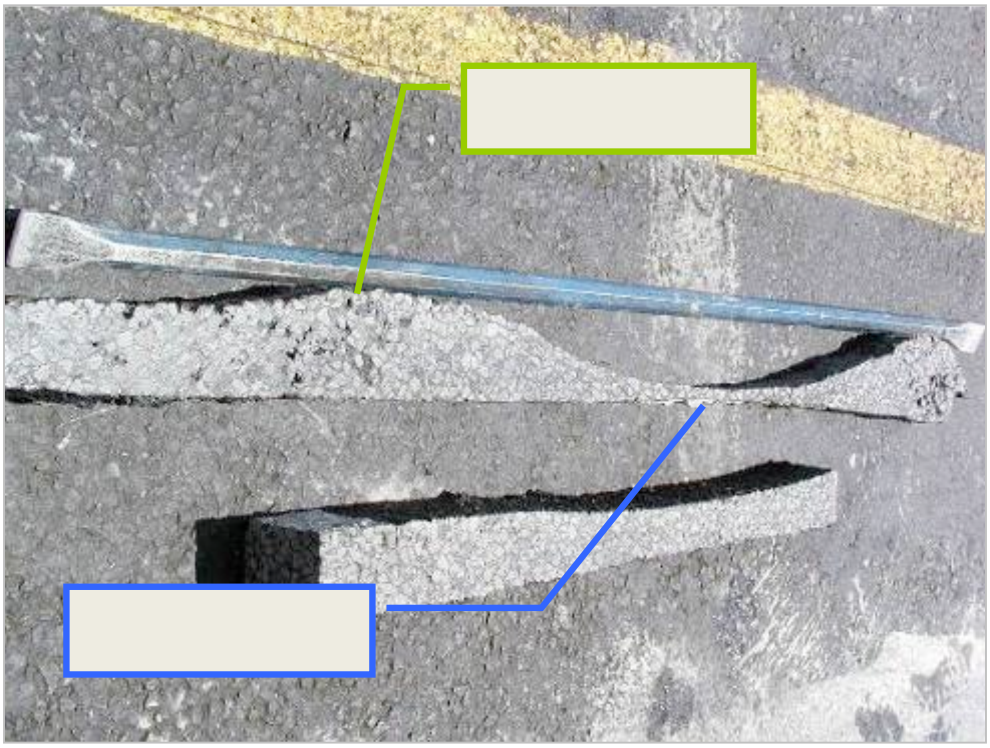

Figure 4: Rut cross section in straddle path and air voids in rut shoulder

PORTMIX™ COMPONENT OPTIMISATION

To obtain the best deformation resistance from an asphalt mix, the approach adopted was to dissect the mix and optimise each component for this attribute.

Ways of improving deformation resistance in a mix are listed in Austroads (2007) [4] :

- Select a larger nominal size mix
- Use an angular or textured aggregate
- Use a stiffer binder or a binder modified to increase the elastic strain component of the total strain
- Adopt a coarser grading
- Reduce air voids but not below 3%
- Increase filler content.

Mix Grading

It is widely recognised that coarse aggregate structures are best for deformation resistance and so forms the basis for Portmix™ grading design. Nevertheless, prescriptive specifications were avoided to ensure detachment from preconceived notions so that free form design could be exercised to optimise the outcome.

Binder Selection Theory

At about the time Boral began its development of Portmix™, new research was emerging from ARRB[3] into alternative binder properties to predict deformation resistance. ARRB investigations had identified that consistency @ 60°C measured with the elastometer, Figure 5, was a poor predictor of rut resistance and to this end the guidelines for polymer modified binders had perhaps inappropriately focused on high consistency values in elastomeric binders.

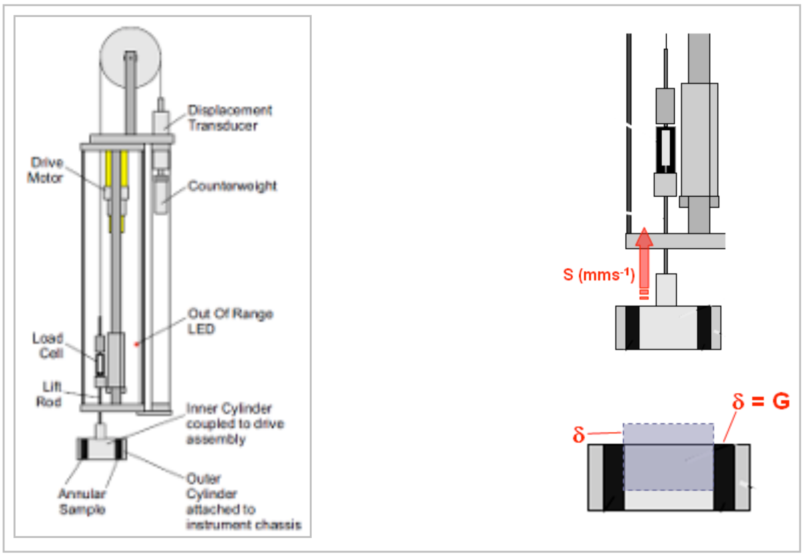

Figure 5: ARRB Elastometer and operating parameters (Austroads, 2010)

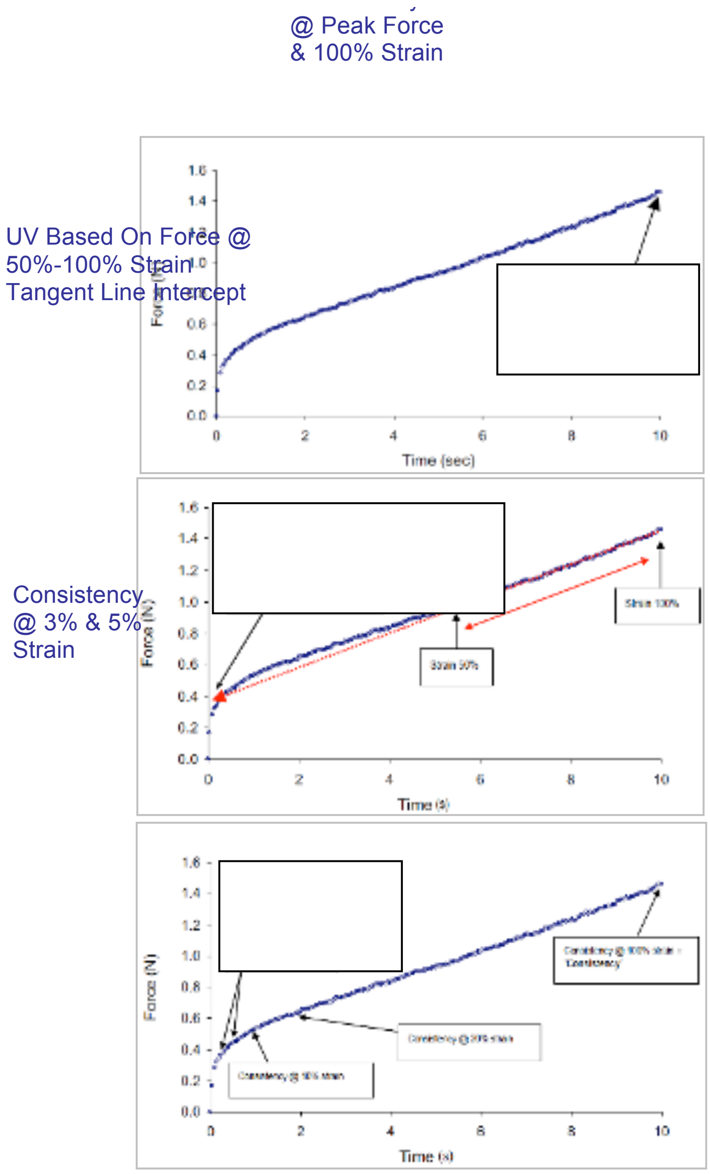

Figure 6: Consistency and underlying viscosity measurement with elastometer (Austroads, 2010)

The traditional view of purely viscous response was superseded and at the time, the alternative parameter found to have better correlation to rutting measured by the wheel tracking test (WTT) was 'Underlying Viscosity'. This value is calculated using the force at the intercept of the tangent taken at 50%-100% strain with the Y-axis.

The mapping of parameters against final rut depth measurements from the wheel tracker has continued since then and Austroads now reports that a much higher correlation is achieved with 3% and 5% strain from the consistency curve.

Figure 6 shows the different parameters considered against WTT rut depth and Table 1 gives respective correlation coefficients for linear relationships on a log-log scale of the respective variables.

To develop the first generation of Portmix™ several binders were tested and results used to identify the most suitable binder for the purpose.

Importantly, the data (shown in Figure 7) revealed that binders with the highest consistency did not necessarily have the highest underlying viscosity.

Elastometer parameters	R^2
Consistency @ 3% strain	0.93
Consistency @ 5% strain	0.93
Consistency @ 10% strain	0.90
Underlying viscosity (20/40 method)	0.89
Consistency @ 20% strain	0.83
Underlying viscosity (50/100 method)	0.69
Consistency (@ 100% strain)	0.60
Elastic recovery	0.39
Softening point	0.36

Table 1: Correlation of elastometer output to wheel tracking (Austroads, 2010)

Binder Testing

The results of a number of binders tested in the elastometer to determine consistency and underlying viscosity are given in Figure 7.

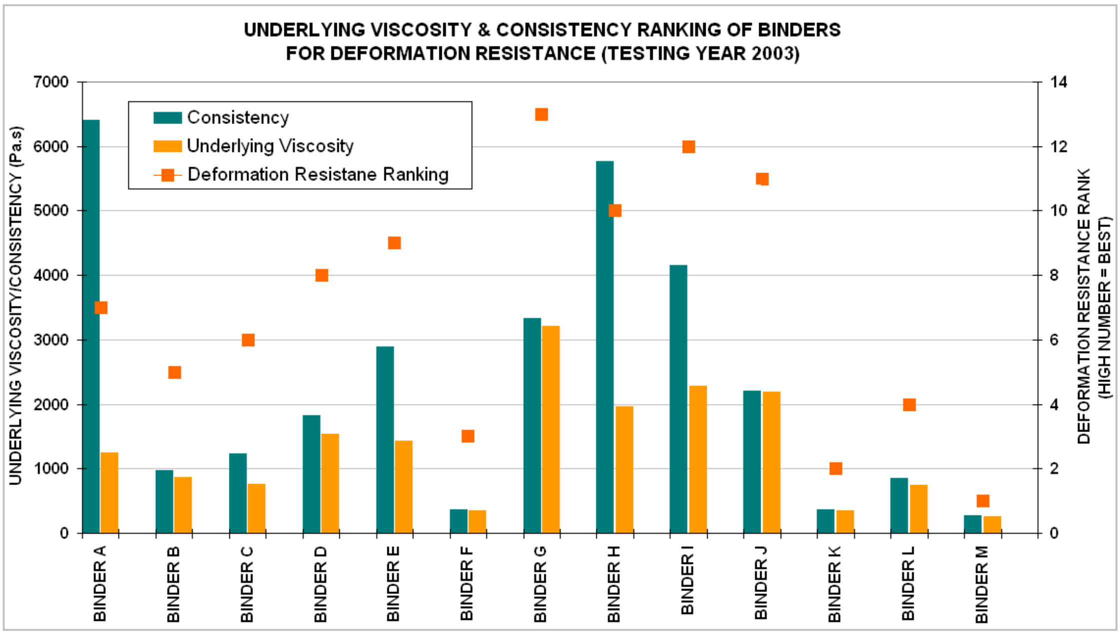

Figure 7: Results from ARRB tests commissioned by Boral for a range of binders measuring consistency and underlying viscosity

Modified binders with high consistency values did not necessarily have a high underlying viscosity value and this changed the criteria for choosing a port binder. Final ranking assigned to binders was based a combination of magnitude and relevance of binder characteristics but also took into consideration any evidence and experience available for asphalt mix performance, both in the lab and field, with each binder.

PORTMIX^{TM}'S UNIQUE WTT PERFORMANCE

Port operators have issued a unique specification for rut resistant asphalt since the late 1990s. This specification has been refined and developed by Boral backed by the results of extensive testing on binder and mix characteristics as well as wheel tracking tests. The specification now also provides guidance on production and placement of Portmix^{TM}.

The cornerstone of the Portmix^{TM} specification continues to be the wheel tracking test. Critical settings on the standard Austroads wheel tracking test method, AG:PT/T231, have been modified to attempt to simulate the significantly harsher conditions experienced in container handling facilities.

The key differences are:

- number of passes applied to the sample has been increased to 60,000 passes instead of the standard 10,000 passes
- test temperature has been increased to 65°C instead of the standard 60°C

At the time it was estimated that 60,000 passes represented about 5 years of loading at a representative Melbourne port facility. Today, it is recognised that this number of passes also represents a reasonably practical testing limit as test time is approximately 10,000 passes every 4 hours.

GUIDE TO PAVEMENT TECHNOLOGY PART 4B: ASPHALT - TRACK DEPTH VALUES

These changes are shown in Table 2.

N/A

Test Elements	Standard	Boral Portmix
Wheel size	200 mm outside diameter wheel with 10 mm of rubber tread by 50mm wide	
Tread	smooth with an IRRD hardness of about 80 - 90	
Table travel	250 mm at a frequency of 22 back and forth motions per minute	
Vertical load	700 N	
Test method	**AG:PT/T231**	**AG:PT/T231 (Modified)**
Test temperature	60°C	**65°C**
Termination conditions (cycles)	10,000	**60,000**
Termination conditions (rut depth)	15	

Table 2: Elevated settings for Wheel Tracking Test as applied to Portmix™

Target Final Rut Depth

Despite the heightened test conditions a target for final rut depth is much lower and is set at 2.5mm.

The onerous nature of these test parameters stands out when compared to typical tracking depths expected in highway traffic applications as shown Table 3 from Austroads and Table 4 from VicRoads which are for standard conditions.

Typical tracking depths for laboratory specimens (mm)

Superior performance	Good performance	Medium performance	Low performance
<3.5	3.5–8	8–13	> 13

Table 3: Thresholds for final rut depths of road mixes (Austroads, 2006)

Table 11 – Resistance to Deformation

Asphalt Size and Type	Maximum Tracking Depth @ 60°C (mm)
14HP, 20SP	5
14V, 14HG, 20SG and 20SS	6
10HP	8
[illegible]H, 10V 10HG and 20SI	9
10H	11

Standard Test At 10,000 Cycles

Portmix™	
Parameter	**Value**
Passes	60,000
Test Temperature	65°C
Target Rut Depth	2.5 mm

Table 4: Guidelines to tracking depth for typical VicRoads mixes compared to Portmix™

NEXT GENERATION PORTMIX$^{\text{TM}}$

The latest improvements associated with Portmix$^{\text{TM}}$ are:

- The use of binder with improved fuel resistance
- Continued optimisation of key ingredients;
- The development of a full performance specification; and,
- Incorporation of long term performance monitoring results.

Portmix$^{\text{TM}}$ Fuel Resistance Performance

Development work completed in 2011 has identified various changes that can be made to binder constituents to improve the resistance of Portmix$^{\text{TM}}$ to withstand fuel and lubricant spills. Testing was carried out in accordance with "*EN 12697-43 – 2005 Test methods for hot mix asphalt – Part 43: Resistance to fuel"*. After 180 hours of partial immersion in diesel, the mass loss in a mix with binder used for Portmix$^{\text{TM}}$ had less than half the mass loss experienced by a C320 or multigrade binder.

Soaking for 24 hours in accordance with standard test methods indicates significantly better performance again, and the difference in the level of disintegration is shown in Figure 8.

Figure 8: Fuel resistance test showing improvement with Portbinder

Continued Optimisation of Key Ingredients

Research into the proportions of each ingredient and combinations thereof has revealed that further improvement is possible. New, 'hi-tec' binders currently under trial appear to give even better rut resistance performance for Portmix$^{\text{TM}}$. Figure 14 shows final rut depths as low as 0.6 mm for the demanding conditions of the Portmix$^{\text{TM}}$ version of the wheel tracking test when using laboratory prepared samples.

Portmix$^{\text{TM}}$ Performance Specification

A full performance based specification was developed for Portmix$^{\text{TM}}$ based on results to-date and mindful that such a document should not limit the scope for optimising mix components both in the design and manufacturing stages. Its major focus is wheel track testing and air voids measurement in the field. Variations to target gradings and binder content are reported as an exception report.

The target value for a sieve or the target binder content is simply 'zeroed' and the difference between the actual and target is reported along with production tolerance bandwidths, an excerpt of which is shown in Figure 9.

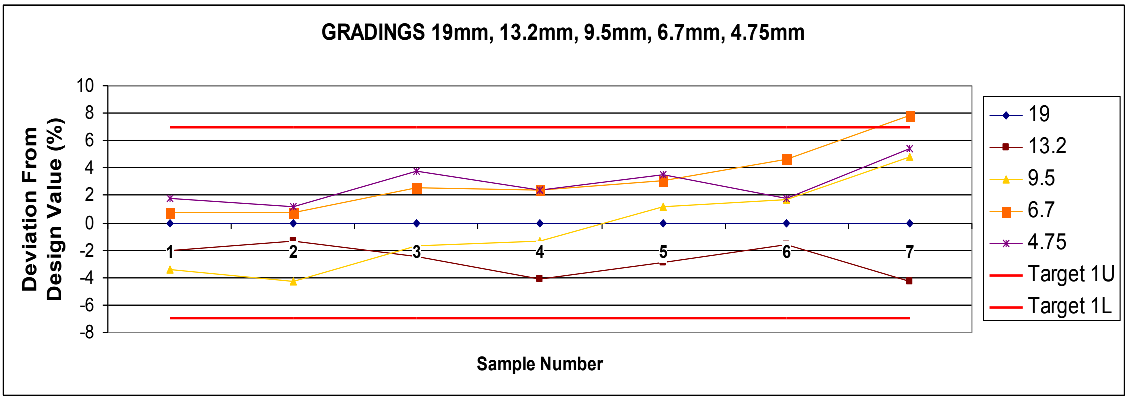

Figure 9: Exception report showing achieved grading relative to design (target)

Field Performance Monitoring

Field performance of first generation Portmix™ was monitored by visual observation and ruts were measured by straight edge testing. The development of second generation Portmix™ has also seen the introduction of field core testing in the wheel tracker thereby facilitating wheel track testing of samples extracted from the field at various intervals during service life. As shown in Figure 10, results on cores extracted from the field between the 6 and 12 month period compare best with those measured on laboratory prepared samples of design mix.

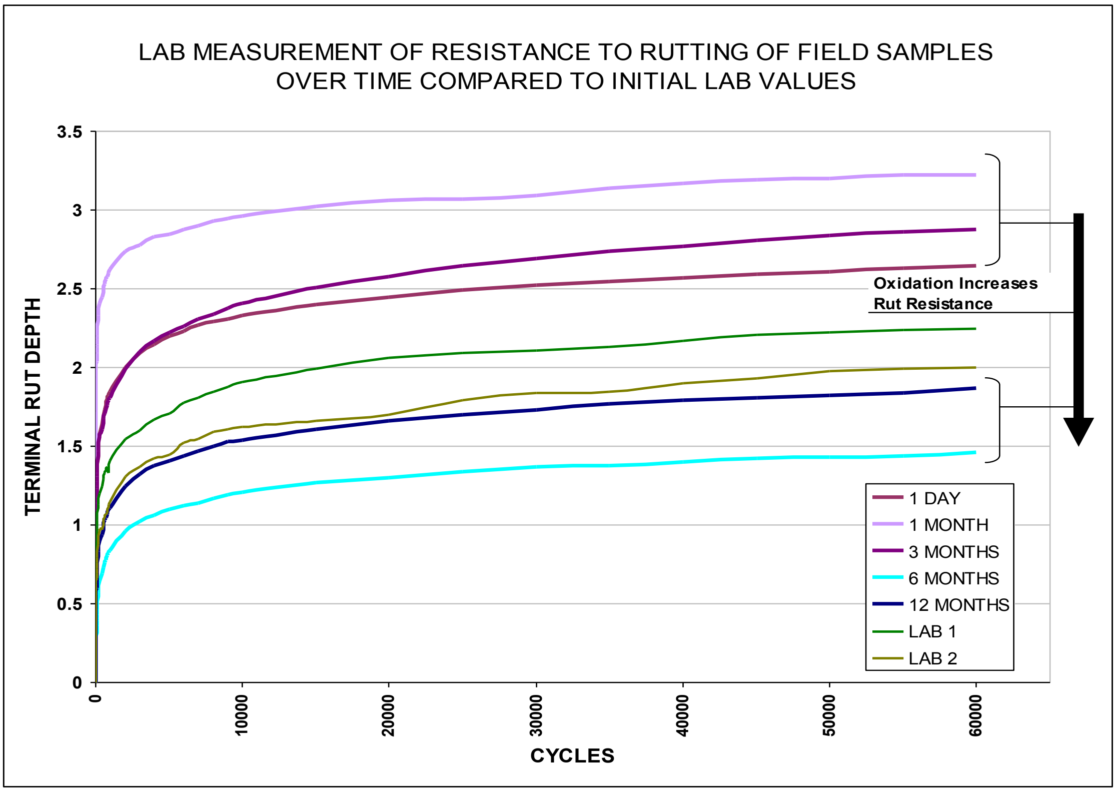

Figure 10: Wheel tracking comparison of lab and field samples over time

It is important to note that this comparison does not mean rutting has occurred in the field but rather that a core extracted from the field at a certain point in time behaves like a laboratory prepared sample of design mix when subjected to the wheel tracking test. The benefit of such a comparison is that should rutting occur in future, then a core extracted at that time may provide an offset between field and laboratory rut values.

VALUE ENGINEERING PROPOSITION

Wheel tracking values, irrespective of whether they are derived at standard or the elevated test conditions, cannot be converted to an input such as a shift factor applied to the existing mechanistic design method. Consequently, a value engineering exercise is necessary to recognise the different performance levels in the wheel tracking test and the potential benefit from Portmix™ in a pavement composition. One difference is that Portmix™ can be laid in thicker layers than normal wearing courses and in doing so replaces some of the intermediate course.

Wheel tracking results suggest that Portmix™ may offer at least double the serviceability of standard mixes, and that design needs to be aligned to perpetual pavement concepts in lieu of classical fatigue theory and bottom-up cracking.

CONCLUSION AND SUMMARY

The journey to develop a deformation resistant asphalt for ports and container terminals that commenced at the turn of the century is now delivering the second generation of Portmix™. A sufficient database of performance results exists to indicate a correlation to field performance that has been observed over 10 years.

Portmix™ has developed from a laboratory notion to a viable asphalt mix for extreme conditions and is supported by a specification written for national use. Portmix™ has been used in South Australia, Queensland, Victoria, New South Wales and Western Australia thereby accounting for the range of climatic conditions across the country.

Importantly, the mix has also been successfully used in highway applications at 'recidivist' rut sites when a host of other asphalts have failed prematurely.

Further research is underway to develop an upgraded new generation Portmix™ incorporating new binders and more detailed volumetric analysis.

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AUTHOR BIOGRAPHIES

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Thomas Melvin is Technical Manager for Boral Asphalt, Victoria. He has worked in the construction materials industry since 1978 covering quarry, concrete and asphalt product development. He commenced with Boral as Technical Services Manager in 1995. He manages the research and development facility at Deer Park and is also responsible for 7 NATA accredited asphalt quality control laboratories throughout Victoria. Thomas has extensive experience in product development, production facilities, contracting and field testing of road construction materials. He has an Advanced Diploma in Laboratory Management from Box Hill Institute of Technology.