Sustainability & Environment

Dense graded crumb rubber asphalt development for sub-tropical climate

Laszlo Petho[1], Chris Lange[1], Michael Lyons[2], Steve Forbes[2]
[1]Fulton Hogan Infrastructure Services, Brisbane, Australia, [2]Moreton Bay Regional Council, Brisbane, Australia

Abstract

The use of crumb rubber modified (CRM) binder can provide increased durability and cracking resistance. Although crumbed rubber modified bitumen is used extensively worldwide, the application has been very limited in asphalt mixes in Australia and has not been used in dense graded asphalt due to the complexity of the design. The first of its kind in Queensland, a research and development (R&D) project with the Moreton Bay Regional Council (MBRC) was established to provide a fit for purpose solution using crumb rubber technology in dense graded asphalt. The paper discusses the crumb rubber binder blend properties. Further to conventional test methods, the benchmarking of the rheological properties was carried out by means of the dynamic shear rheometer. Details on the volumetric properties and performance-based test results are provided in the paper and manufacturing, construction and field procedures are also discussed. Based on the laboratory and field validation it was concluded that the newly developed dense graded crumb rubber mix is well balanced and has a high performance. Additionally, it uses environmentally friendly and sustainable technology while potentially reducing maintenance costs.

This paper was first published in 2020 in version 1.0 of the proceedings of the 7th E&E Congress. This second edition (version 1.1.) of the proceedings is published in June 2021. The content of this paper has not changed, but the author(s) may have provided additional information in the form of an annex.

1. INTRODUCTION

Every year approximately 48 million tyres reach their end-of-life in Australia. Unfortunately, a substantial proportion of these end up in land fill sites. Stockpiled tyres in yards or landfill sites are both an environmental hazard and a fire danger. They also provide breeding grounds for mosquitos. These end-of-life tyres are a potentially valuable resource for recycling. The use of recycled tyres in crumb rubber modified bitumen is of significant environmental benefit. Although asphalt using elastomer and plastomer modified bitumen for asphalt surfacing mixes is used extensively in Australia, crumbed rubber is not.

Although bitumen only constitutes approximately 5% of an asphalt surfacing mix, it is the fundamental component in achieving cohesion between crushed aggregate and filler components. Although a relatively small proportion of the mix, bitumen's properties are critical to the performance of the asphalt.

The rubber crumb used to manufacture rubber modified bitumen is sourced from used car and truck tyres which are granulated to produce a finely ground product. This is wet blended with bitumen at a high temperature through a specialised mixing process to produce a homogenous binder. The binder is designed to meet specific performance properties and tested prior to being supplied to the asphalt plant for incorporation into the asphalt mix.

The use of crumb rubber modified (CRM) binder can provide increased durability and cracking resistance. Although crumbed rubber modified bitumen is used extensively worldwide, the application is limited in asphalt mixes in Australia. CRM binders are typically used in two types of asphalt mixes, gap graded asphalt (GGA) and open graded asphalt (OGA). When compared with conventional asphalt types, experience shows that crumb rubber modification enhances the in-situ performance of asphalt mixes.

CRM binders have not been used in dense graded asphalt in Queensland due to the complexity of the design. In an effort to overcome that, Fulton Hogan embarked on a research and development (R&D) project with the Moreton Bay Regional Council (MBRC) to develop a fit for purpose solution using crumb rubber technology in dense graded asphalt. It was the first of its kind in Queensland, therefore the development process had to be conducted carefully. Queensland has a sub-tropical climate, which is different to other Australian states. Thus, the design had to consider the importance of preventing permanent deformation under such a climatic condition [1].

It was envisaged that such an asphalt mix would deliver extended in-service life for asphalt surfacing while providing an environmentally friendly and sustainable technology. Moreton Bay Region is a local government area north of the Brisbane metropolitan area in South East Queensland. With a population of over 425,000, Moreton Bay Region is the third largest local government area in Australia and has an extensive road network to maintain.

The asphalt mix was formulated to minimise the risk of surface distress, including ravelling, rutting, shoving and cracking while handling local traffic on pavement surfaces from residential streets up to arterial connection roads. The adopted methodology for producing an asphalt mix that can provide such a fit-for-purpose solution is discussed in detail in this paper. This includes both the volumetric and performance-based mix design process and the binder assessment.

2. MATERIALS AND METHODS

2.1. R&D project objectives

Crumb rubber asphalt mixes normally require space for the partially digested swollen crumb particles. This adds to the complexity of the Marshall mix design process of a dense graded asphalt with crumb rubber binder. The design criteria for the dense graded asphalt mix can be summarised as follow:

- Utilise 50 Marshall blows for laboratory compaction, normally required for asphalt mixes in Queensland
- Use current dense graded asphalt mix as a starting point according to current Transport and Main Roads (TMR) Specification [2]
- Avoid introducing significant changes to existing combined aggregate grading to avoid any change in surface characteristics
- Target air voids content and volumetric properties close to the Brisbane City Council (BCC) Type3 [3] asphalt mix used on MBRC road network as wearing course
- The performance of the new asphalt mix should meet the performance of the Type3 mix as a minimum
- Ensure good workability of the new asphalt mix that low in situ air voids can be achieved
- Optimise mix composition for durability without risking the rut resistance.

In order to maximise the recycling potential, 15% recycled asphalt pavement (RAP) was added to the dense graded crumb rubber asphalt mix, which will be referred to as AC14H(15R)(CR) in this paper. The Type3, which incorporates multigrade M1000 bitumen and 20% RAP will be referred to as Type3(M1000)(20R).

2.2. Binder development and selection

Some overseas experience has shown that dense graded asphalts can be produced using crumb rubber binder (CRB). However, this process, including binder blend design, mix design, testing, production and field procedures, have not been trialled, harmonised or validated in Australia for sub-tropical conditions.

It was decided that the binder used in the dense graded asphalt mix would be a pre-blended crumb rubber binder produced at a PMB plant. Accordingly, it has to be ensured that the rubber crumb particles were not completely digested and dissolved in the bitumen matrix. An alternative application of crumb rubber is a dry process, where the rubber crumb is added as aggregate material into the asphalt mixing process. This application method produces potential fuming and presents a possibility of non-uniform mixing. Therefore, such an application was not considered for this development.

In the wet blended process, the tyre rubber is blended into the binder at a polymer modified binder (PMB) manufacturing facility for use in the asphalt plant as finished product. The homogeneous bituminous binder has excellent storage stability and improved material properties over conventional binder. The different crumb rubber binder (CRB) manufacturing methods are discussed in detail and reported by others [4].

The material used in this development was rubber crumb produced in Australia (Figure 1). Table 1 shows the grading of the rubber crumb used compared with the Arizona spec section 1009 - Type B grading. As can be seen in Table 1, the currently available crumb rubber complies with Arizona spec 1009, Type B requirements [5].

Figure 1: Rubber crumb used for manufacturing crumb rubber binder

Table 2. Particle size distribution of rubber crumb particles

US Sieve No#	Sieve size (mm)	Closest AS sieve (mm)	Arizona specification section 1009 Type B		Used in CRB
			Lower limit	Upper limit	
8	2.38	2.36	N/A	N/A	100
10	2	N/A	100	100	N/A
16	1.19	1.18	65	100	99.7
30	0.595	0.600	20	100	76.4
50	0.297	0.300	0	45	26.7
200	0.074	0.075	0	5	1.1

CRB for gap-graded asphalt – GGA – and open graded asphalt – OGA is specified in pilot specification PSTS112 [6] issued by TMR; this pilot specification is based on the Californian experience [7]. The minimum rubber crumb content for these two specialised asphalt applications has to be minimum 18% per total binder weight. This was considered high and unsuitable for dense graded asphalt application, therefore a lower percentage of crumb rubber utilised and a minimum of 10% rubber crumb content was applied.

2.3. Conventional binder testing

For benchmarking, the conventional properties of different polymer modified bitumen (PMB) [8] and a multigrade (M1000) bitumen [9] were compared. These bituminous products are widely available on the Australian market. Multigrade bitumen is used by local councils in Southeast Queensland (SEQ). The primary properties for PMBs are viscosity at 165°C, softening point and torsional recovery. Since there is no specification framework available for CRB used in dense graded asphalt, referred to as CR(AC) in this paper, the primary properties for PMBs were used. An exception was for viscosity which was tested at 175°C. Since data is available for CRB for GGA, this is used for benchmarking in this paper. To avoid confusion, this crumb rubber binder will be referred to as CR(GGA) in this paper. The properties are summarised in Table 2.

Table 2. Conventional properties of various binders

Binder type	Viscosity @ 135°C	Viscosity @ 165°C	Viscosity @ 175°C	Torsional recovery @ 25°C, 30s (%)	Softening point (°C)
Test method	AS2341.4 [10]	AGPT/T111 [11]		AGPT/T122 [12]	AGPT/T131 [13]
M1000	0.721	N/A	N/A	N/A	N/A
A10E	N/A	0.587	N/A	76	98.0
A35P	N/A	0.395	N/A	21	66.5
CR(GGA)	N/A	N/A	1.900	23	69
CR(AC) (10/9/19)	N/A	N/A	1.050	34	65
CR(AC) (11/9/19)	N/A	N/A	0.863	32	62

It is of particular importance that the CRB maintains its properties over a period of time. The CR(AC) was stored for 24 hours in the asphalt plant's bitumen tanks. On 10 September 2019 a small scale (50 tonnes) yard trial was carried out prior to the large scale (250 tonnes) roadworks on 11 September 2019; according to Table 2, the properties of the CR(AC) did not change significantly within 24 hours for two consecutive production shifts.

2.4. Dynamic shear rheometer (DSR) testing

Given the complex nature of any CRB, its selection and assessment cannot be done by only using conventional binder test methods. Therefore, further to the conventional binder properties (Table 2), the CR(AC) along with the other binder types listed in Table 2, were assessed by the dynamic shear rheometer (DSR). The DSR was performed according to the AASHTO test method [14]. The total response of an asphalt binder to load consists of elastic (recoverable) and viscous (non-recoverable) components. The complex modulus and phase angel represents a measure of the response at high-temperature of the asphalt binder [15].

For the assessment the test results of G* (complex modulus) and δ (phase angle) at 60°C and 10 rad/s are shown in Table 3. A general correlation between $G^*/\sin\delta$ and rutting susceptibility is that a binder with a higher $G^*/\sin\delta$ will produce an asphalt mix with a lower rutting susceptibility [16]. Considering the values in Table 3, the CR(AC) binder used for dense graded asphalt shows a very high $G^*/\sin\delta$ value, therefore its susceptibility to rutting was expected to be extremely low. This expectation was in line with the wheel-tracking test (Section 4.2), performed on the production mix. The CR(AC) sampled at the time of the yard trial on 10 September 2019 was not tested for DSR therefore it is not shown in Table 3.

Table 3. Performance based properties of various binders

Binder type	DSR viscosity @ 60°C, 1 rad/s	Complex modulus (G*) @ 60°C, 10rad/s	Phase angle (δ) @ 60°C, 10rad/s	$G^*/\sin(\delta)$
Test method	AASHTO T 315–12 [14]			
M1000	1183	9801	80	9.9
A10E	3243	9603	47	13.1
A35P	1109	6129	69	6.6
CR(GGA)	3520	16620	59	19.4
CR(AC) (11/9/19)	1780	6713	64	10.3

The DSR temperature-frequency sweep test was used for obtaining the G* and δ values at a wide range of temperatures (20 to 70°C) and frequencies (0.1 to 62.83 rad/s) for the construction of a series of master curves. The latter is normally utilised to compare the different binders for a wide range of temperature and frequency and not only at a single test point. The complex modulus master curves, as a complex presentation of the binder properties, are summarised in Figure 2. Based on Table 3 and Figure 2 it can be concluded that the CR(AC) used for dense graded asphalt shows higher performance than a plastomeric modified binder (A35P) and a multigrade binder (M1000). Its performance would not reach the levels of an A10E binder; however, that was not the objective of the development. Also, CR(AC) used for dense graded asphalt does not reach the properties of the CR(GGA) used for GGA asphalt mix [6]. It should be however noted that due to the extremely viscous nature of CR(GGA) it's application in dense graded asphalt is not considered suitable. Using CR(GGA) binder in dense graded asphalt would not allow for good workability of the asphalt mix and good workability was a primary objective of the development.

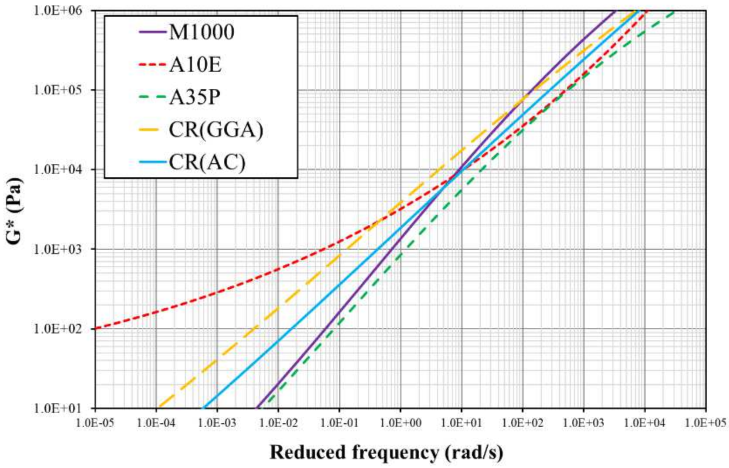

Figure 2: Complex modulus master curves of various binders

3. ANALYSIS OF THE RESULTS

3.1. Production control and in situ testing

CRB binders normally require high production and paving temperatures due to the extremely viscous nature of the binder. The warm mix additive, which was an important aspect of the whole development, enabled lower production and compaction temperatures without compromising the field procedure. Mixing temperatures were in the range of 155 to 166°C for the AC14H(15R)(CR). Without the warm mix additive a much higher production and paving temperature would be required for such an asphalt mix. Continuous production tests were performed for both the AC14H(15R)(CR) trial mix and the BCC Type3(20R)(M1000) control mix. Testing included particle size distribution (PSD), binder content and maximum density. The volumetric properties are summarised in Table 4. It was found that not all of the metered binder could be recovered in the bitumen content test using toluene, a solvent predominantly used in Australia. Therefore, the procedure described in the South African Bitumen Association Manual 19 [17] was used. Accordingly, a binder factor of 0.89 was established for crumb rubber binder, i.e. 89% of the metered binder can be reclaimed with the test. The establishment of this value was critical to ensure the volumetric mix design is correct and acceptance test results are interpreted correctly. This value is listed as corrected bitumen content in Table 4.

Table 4. Volumetric properties of the asphalt mixes based on large scale production testing

Mix property	AC14H(15R)(CR) Yard trial		AC14H(15R)(CR) Road trial		Type3(20R)(M1000) Road trial	
	Sample		Sample		Sample	
	1	2	1	2	1	2
Mix temperature at the asphalt plant (°C)	159	159	155	166	160	166
Bitumen content (%)	4.8	4.6	4.8	4.8	4.7	4.6
Bitumen content (corrected) (%)	5.4	5.1	5.4	5.4	N/A	N/A
Maximum density (t/m3)	2.643	2.638	2.639	2.636	2.659	2.666
Air voids (%)	4.6	3.5	4.4	4.4	5.1	4.8
Voids in mineral aggregate (VMA) (%)	17.3	15.7	17.1	17.1	16.5	16.0
Voids filled with binder (VFB) (%)	74.2	78.3	75.0	75.2	69.1	69.8

Binder volume (%)	12.7	12.2	12.7	12.7	11.4	11.2

Due to the viscosity of the CR(AC), optimal compaction efficiency was achieved before the mat cooled below 145°C. In situ temperature and density measurement and densification of the mat tested by the pavement quality indicator (PQI). The paving operation was adjusted according to the observed temperatures by decreasing the gap between the paver and the rollers. The work site is shown on Figure 3.

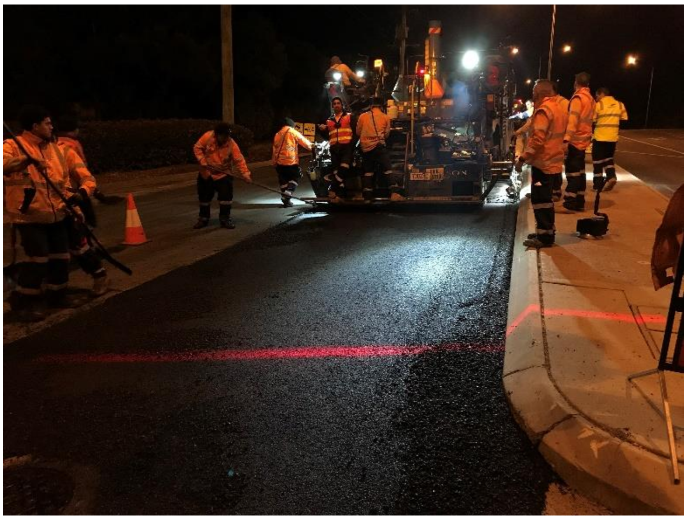

Figure 3: Paving dense graded crumb rubber asphalt mix

Both asphalt mixes were laid at 45 mm nominal thickness. Cores extracted from the finished pavement were tested for air voids, using the saturated surface dry (SSD) method (Table 5). In Australia the SSD method is normally applied for asphalt concrete mixes. In situ compaction of Type3 asphalt mixes are normally assessed based on relative compaction [3], which is calculated according to the following equation.

$$relative\ compaction = \frac{compacted\ density}{maximum\ density} \times 100$$

Dense graded asphalt mixes are assessed based on the air voids content, therefore the relative compaction of the Type3 mix had to be recalculated according to the following equation:

$$air\ voids = 100 - relative\ compaction$$

Based on Table 5 it can be concluded that the workability of the trial mix AC14H(15R)(CR) was not compromised as good in situ compaction could be achieved with very low standard deviation. The latter indicates that homogeneity of the mix was not an issue.

Table 5. In-situ air voids

Mix type	SSD air voids (%)	
	Average	Standard deviation
AC14H(15R)(CR) Yard trial	4.7	1.13
AC14H(15R)(CR) Road trial	4.6	0.42
Type3(20R)(M1000) Road trial	4.3	1.03

3.2. Wheel-tracking test

In order to assess any risk associated with the stability of the mix, a wheel-tracking test was carried out according to AGPT/T231 [18] for the AC14H(15R)(CR) asphalt mix at the mix design stage. The test was performed at normal test parameters, which is 10,000 passes and 60°C. For benchmarking purposes bulk production samples were taken of the AC14H(15R)(CR) and Type3(20R)(M1000) asphalt mixes and tested for wheel-tracking. The results are summarised in Figure 4. For further benchmarking an AC20H(600), a standard asphalt base layer mix with Class 600 binder, and a BCC Type2(M1000), a fine wearing course asphalt mix with M1000 multigrade bitumen was added to the chart [19]. The wheel tracking depth for the newly developed crumb rubber dense graded mix is considered very low both in absolute values [20] and when benchmarked against other mix types (Figure 4).

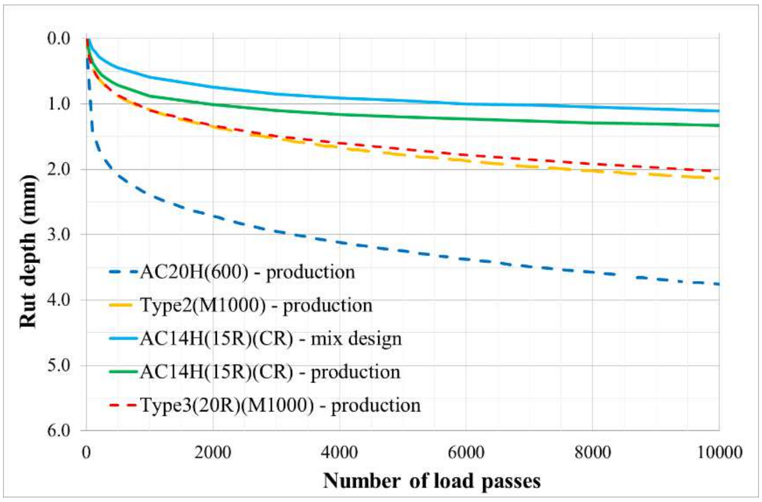

Figure 4: Wheel-tracking charts of the newly developed dense graded crumb rubber mix compared with other mix types for benchmarking

3.3. Moisture sensitivity

In Australia the modified Lottman test is generally used for assessing the moisture sensitivity of an asphalt mix [21]. The test method for the tensile strength ratio (TSR) lists the freeze-thaw treatment as an option; however, it was used for testing both AC14H(15R)(CR) and Type3(20R)(M1000) asphalt mixes. The results are summarised in Table 6; while both the dry and wet tensile strength showed lower value for the AC14H(15R)(CR) compared to Type3(20R)(M1000), it does not indicate substandard performance since the modified Lottman test is a performance indicator for moisture sensitivity through the TSR value. The test returned marginally lower TSR value for the AC14H(15R)(CR) compared to Type3(20R)(M1000) and it can be observed that the use of CR(AC) did not have a detrimental impact on the TSR value and the mix is considered durable. Also, in Queensland the TMR Specification [2] requires that the minimum wet tensile strength is 600 kPa for any asphalt mix and the TSR value is above 80%.

Table 6. TSR results

Mix type	Dry tensile strength (kPa)	Wet tensile strength (kPa)	Tensile strength ratio (%)
AC14H(15R)(CR)	762	719	94
Type3(20R)(M1000)	1427	1443	101

3.4. Resilient modulus test

As part of the validation process resilient modulus testing was performed according to the Australian Standard [22]; it was completed on a series of laboratory made briquettes. The samples were tested for resilient modulus at 25°C and the results are summarised in Table 7. The standard test conditions require that samples are prepared at an air voids content of 5%±0.5%. It was found that the trial asphalt mix showed a high resilient modulus value; compared to the Type3 asphalt mix there is no adverse effect on this engineering property.

Table 3. Resilient modulus results

	AC14H(15R)(CR)		**Type3(20R)(M1000)**	
Sample	**Air voids (%)**	**Resilient modulus @ 25°C (MPa)**	**Air voids (%)**	**Resilient modulus @ 25°C (MPa)**
1	5.3	5240	4.8	5530
2	4.8	6510	4.9	6320
3	5.0	5320	4.8	5460
Average	5.0	5690	4.8	5770

4. SUMMARY AND CONCLUSIONS

The successful joint venture in this R&D project is considered a big step towards an environmentally improved and sustainable future. CRM binders have not been used in dense graded asphalt in Queensland due to the complexity of the design. The research and development (R&D) project was launched to develop a fit for purpose solution using crumb rubber technology in dense graded asphalt.

It was the first of its kind in Queensland. The characterisation of the different asphalt mixes using performance based test methods demonstrated no inferior performance to currently used Type3 dense graded asphalt mix. Trials in other climatic conditions indicated no inferior performance to asphalt mixes with C320 binder [23]. One of the factors which has limited the uptake of crumb rubber asphalt has been cost. Crumb rubber gap-graded asphalt – GGA – and open graded asphalt – OGA are extremely high performing asphalt mixes; however, their use is linked to specific applications, such as mitigating block cracking or preventing water spray respectively. Due to their high binder content (> 7.5% by mass) and associated cost their use is limited to specific road types and may not be cost effective for large scale roll out in a local council environment. Dense graded crumb rubber asphalt mixes, as demonstrated in this paper, require higher binder content compared to conventional dense graded asphalt mixes; however, the associated cost increment is considered marginal and may allow their uptake into local government markets a viable option.

Based on the laboratory and field validation it can be concluded that the new mix design is well balanced and high performing. It uses environmentally friendly and sustainable technology that can reduce maintenance costs [4].

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of SAMI Bitumen Technologies for the binder supply. Also, many thanks to Warrick Cutler from Fulton Hogan for the dedicated work provided for the preparation of the trial.

REFERENCES

[1] Petho, L & Bryant, P, 2016, ‘EME2 fatigue properties and pavement design in a sub-tropical climate’, 8th RILEM international conference on mechanisms of cracking and debonding in pavements, 7-9 June 2016, Nantes, France, Springer, pp. 431-436.
[2] Transport and Main Roads Specifications, MRTS30 Asphalt Pavements, March 2019, TMR, Brisbane.
[3] S310 Supply of Dense Graded Asphalt, Reference Specifications for Civil Engineering Work, Brisbane City Council, Brisbane.
[4] Denneman, E, Lee, J, Raymond, C, Choi, Y, Khoo, KY & Dias, M 2015, P31 and P32: Optimising the use of crumb rubber modified bitumen in seals and asphalt (year 1 – 2014/15), National Asset Centre of Excellence, Brisbane, QLD.
[5] Arizona Department of Transportation, Standard Specifications for Road and Bridge Construction, 2008.
[6] PSTS112 Project Specific Technical Specification, Crumb Rubber Modified Asphalt, Transport and Main Roads Specifications, February 2019.
[7] California Department of Transportation 2010, Standard specifications: rubberized asphalt concrete (type G), section 10.1, Caltrans, Sacramento, California, USA.
[8] AGPT-T190, Specification framework for polymer modified binders.
[9] AS 2008, Bitumen for pavements.
[10] AS/NZS 2341.4:2015, Methods of testing bitumen and related roadmaking products Determination of dynamic viscosity by rotational viscometer
[11] AGPT/T111, Handling viscosity of polymer modified binders, (Brookfield thermosel).
[12] AGPT/T122, Torsional recovery of polymer modified binders.
[13] AGPT/T131, Softening point of polymer modified binders.
[14] AASHTO 2012, Standard method of test for determining the rheological properties of asphalt binder using a dynamic shear rheometer (DSR), T 315–12, AASHTO, Washington, DC, USA.
[15] Asphalt Institute 2011, MS-26 asphalt binder handbook, Asphalt Institute, Lexington, Kentucky, USA.
[16] Stuart, KD & Izzo, RP 1995, ‘Correlation of Superpave G*/Sin with rutting susceptibility for laboratory mixtures’, Transportation Research Record, no. 1492, pp. 176-83.
[17] Manual 19 – May 2018 Guidelines for the design, manufacture and construction of bi-tumen-rubber asphalt wearing courses, South African Bitumen Association.
[18] AGPT/T231, Deformation resistance of asphalt mixtures by the wheel tracking test.
[19] Petho, L, Denneman, E, 2016, ‘Implementing EME2, the French high modulus asphalt in Australia’, Proceedings of the 6th Euroasphalt and Eurobitume congress held in June 2016, Prague, Czech Republic, European Asphalt Pavement Association, Brussels.
[20] Austroads 2014, Guide to pavement technology: part 4b: asphalt, AGPT04B-14, Austroads, Sydney, NSW.
[21] AGPT/T232 Stripping potential of asphalt - Tensile strength Ratio.
[22] AS/NZS 2891.13.1-2013, Determination of the resilient modulus of asphalt: indirect tensile method.
[23] McArthur, R., Crumb Rubber Asphalt Stanlake Ave trial, Mitcham Council, 18th AAPA International Flexible Pavements Conference 2019, Sydney, NSW.