Asphalt mixture performance and testing

High performing asphalt for racing conditions in sub-tropical climates – the Australian experience

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Abstract

Asphalt surfaces for racing conditions need to be extremely durable to withstand high temperatures and extreme horizontal shear forces. In 2014 a number of sections of the Street Circuit of the City of Gold Coast in Queensland exhibited distress in the form of ravelling. In response, the author of this paper developed a highly engineered asphalt mix to provide a fit for purpose and durable asphalt surfacing product that could withstand the high shear stress of the Australian race cars. The R&D project utilised first principles to develop a highly engineered asphalt material. The asphalt mix was formulated to handle race conditions and minimise the potential for track surfacing failures including ravelling, rutting, shoving, cracking and delamination, all of which have the potential to damage cars, cause accidents and increase vehicle wear and tear. The successful mix design, process and methodology are discussed in detail in this paper. The bitumen selection for this particular application was based on the benchmarking of the rheological properties of different bitumen types by means of the dynamic shear rheometer (DSR). The complex modulus and the phase angle of the different binders, related to race car loading frequency and sub-tropical pavement temperatures, were considered key input parameters. Production and placement of the trial mix design was first carried out on a private race track where performance was monitored under simulated race conditions. With performance parameters set and input from the race car drivers considered, monitoring of the trial section concluded that the asphalt mix was suited for the Surfers Paradise Street Circuit. This paper discusses the complex processes of mix design, trailing, production control, paving and workmanship. The outcomes of post-performance monitoring - with no distress reported after four years in service - is provided in the paper.

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1. INTRODUCTION

Each year the Gold Coast in Queensland, Australia welcomes around 12 million visitors. The City of Gold Coast actively maintains public facilities and supports major events to attract visitors to the bustling tourist city and enhance the experience of visitors. One such event is the V8 Supercars motorsport festival held on the famous Gold Coast Street Circuit. In 2014, routine inspections of the Surfers Paradise V8 Supercar Street Circuit revealed distress from high-shear racing conditions on sections of the pavement. In response to the need for a durable, high performing asphalt surface, a research and development project was launched to develop alternative asphalt mix designs that would meet the demand.

The Surfers Paradise Street Circuit operates as a racetrack for only three days per year. In those three days as many as 12 000 laps are done on the 2.98 km long circuit which includes 15 turns and two chicanes. The Street Circuit is part of the city's road network and its streets have to perform for commuter traffic for the rest of the year. It is therefore critical that the asphalt surfaces of the streets around Surfers Paradise and Main Beach are durable enough to maintain performance for both commuter traffic and racing demands.

In 2014 a number of sections of the V8 Supercar Street Circuit in Surfers Paradise exhibited distress in the form of ravelling under high-shear racing conditions. The research and development (R&D) project outlined in this paper produced a new asphalt surfacing system capable of sustaining the extreme forces generated by V8 motor sport while prolonging pavement life and minimising ongoing maintenance costs.

This paper summarises the methodology and outcome of the R&D project. For the development of this highly engineered asphalt material first principles were used, which is also discussed. In this paper there will be references to the binder and the mix as *new race mix (NRM)* and *new race binder (NRB)* given the paper is providing a summary on the general design methodology and performance.

The asphalt mix was formulated to handle race conditions and minimise the potential for track surfacing failures, including ravelling, rutting, shoving, cracking and delamination. All of these have the potential to damage cars, cause accidents, increase vehicle wear and tear and risk the success of an event such as the V8 Supercar Street Circuit Races that take place on the Gold Coast. The adopted methodology for producing an asphalt mix that can handle the race conditions and minimise the potential for surfacing failures are discussed in detail in this paper. This includes both the volumetric and performance-based mix design process and the binder selection.

2. MIX DESIGN OBJECTIVES

2.1. Past experiences – mix design

There have been various specifications available in Australia for the design and delivery of asphalt mixes for racing conditions and these were usually designed using the Marshall criteria, which included:

- prescriptive target aggregate grading
- prescriptive minimum binder content by mass, not considering aggregate density and its impact on the binder volume
- 50 Marshall blows for laboratory compaction
- target air voids content within extremely tight tolerances
- voids in mineral aggregates (VMA) and voids filled with binder (VFB) if required
- Marshall stability (MS) and flow (MF).

Depending on the project, the moisture sensitivity test may be required, but there are no other performance related or performance based specification requirements for the asphalt mix.

Such an approach is considered extremely prescriptive. It discourages the designer from thinking outside the box, limits the utilisation of locally available aggregates and imported fillers and, by definition, contradicts the volumetric requirements. In addition, there have been no or very limited performance criteria established to predict in situ performance of various design options.

2.2. Past experiences – in-situ performance

Mixes designed, manufactured and placed according to the above methodology performed quite well in many instances. However in many other cases, in engineering terms, they failed catastrophically. In one case, the surface started disintegrating during a racing event, leading to crashes. In another case, a race was halted to conduct immediate repair works. Such a risk is unacceptable on every front, from the safety of the drivers and spectators to the reputational damage of the event organisers and sponsors. Figure 1 shows a badly deteriorated surface on a tight turn (high shear forces) as an example.

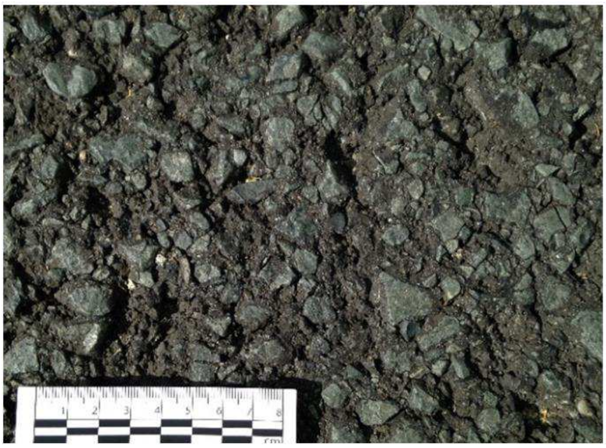

Figure 1: Distressed and deteriorated asphalt surface in the race line

Site investigation and testing of cores extracted from the existing pavement revealed the following:

- In situ air voids above 6%, tested according to the saturated surface dry (SSD) method, show correlation with poor in situ performance.
- Adequate in situ air voids (below 6%) did not guarantee acceptable performance in all cases, even when binder content and volumetric properties were in line with acceptance criteria.

Where the asphalt mix was poorly compacted, it was found that the low compaction level was a result of the unworkable nature of the asphalt mix and poor paving and compaction procedure. This highlighted that there was a need to focus on the paving and compaction operation in order to construct a suitable wearing course which would withstand the extreme forces during a racing event. Workability of the mix has to be considered at the early stages of the mix design. It is also important that the in situ pavement provides suitable support for compaction. As an example, a shallow unbound granular pavement with poor bearing capacity is not considered a good support for compaction and the construction of an asphalt base layer of suitable thickness is inevitable to achieve acceptable in situ compaction of the wearing course.

2.3. Understanding the harsh race conditions

Input was sought from professional car drivers to better understand the forces, driving behaviour, V8 race car characteristics, setups and parameters, which can be summarised as follows:

- depending on the racing event soft or hard slick tyres (no threads) are used; tyres with thread are used only in rain
- a surface with adequate micro- and macrotexture is preferred for racing conditions since it gives a better grip with the slick tyres
- from the organiser point of view a 14 mm nominal aggregate size (19 mm maximum aggregate) is preferred over the 10 mm nominal aggregate size (14 mm maximum aggregate) as this gives a more stable mix based on past experiences
- mixes with larger aggregate sizes are also laid in greater thickness, which ensures adequate quick repairs during or in between races, if required
- V8 race car drivers tend to use the same path on the turns, opposed to F1 race cars, where drivers may use different lines and the full width of the pavement surface
- V8 cars weigh approximately 1560 kg (390 kg per tyre); this weight is distributed on relatively narrow, 280 mm wide tyres, resulting in higher contact stress compared to F1 cars
- breaking and accelerating zones also have complex and extreme stress situations
- due to the setup of the suspension the cars tend to be loaded on two wheels in some corners, which means further increment on the contact stress on the outer wheels
- V8 Supercars currently do not have differentials, which means both rear wheels rotate at the same speed in turns. This means in tight curves and at a relatively high speed there is a constant shear force generated by the outer rear wheel.

Subsequent communication with tyre supplier, Goodyear, confirmed that it is common for both soft and hard slick tyres and for normal racing situations that the tyre temperatures reach a temperature window between 90 and 130°C. This results in further stress added to the wearing course.

The above information was vital in understanding the complex and extreme forces the improved asphalt mix needed to withstand. It is therefore considered that V8 Supercars require asphalt surfacing with higher performance than F1 cars. This also means that learnings and experiences collected on racetracks used for F1 races can only be used as a starting point for designing asphalt mixes for V8 Supercars conditions; however, they cannot be directly adopted.

2.4. Mix design objectives

As discussed before, low in situ air voids of the compacted layer was one of the most critical component of good performance. It should be however noted that the in situ air voids are directly influenced by the design air voids (laboratory) and the in situ compaction (workability) of the mix. An asphalt mix is considered suitable for V8 racing conditions when the following properties are met:

- durable and stable under hot weather and hot tyres
- withstands extreme horizontal shear forces
- provides micro- and macrotexture for good racing conditions
- in situ air voids contents of the compacted mix are between 2% and 6%
- provides good interlock between the particles and relatively high mastic content for a good bond between the aggregates in order to avoid ravelling under hot tyres
- relatively workable to avoid any particle loss and/or water ingress during in service.

The design methodology for the asphalt mix for V8 racing conditions was developed according to the above considerations as follow:

- target aggregate grading close to the maximum density line [1] to allow enough voids in mineral aggregates (VMA) for a relatively high binder content
- adopt 75 Marshall blows for laboratory compaction
- minimum binder content of 5.4% for a combined aggregate density of 2800 kg/m^3 and binder film index (BFI) to be reported
- target laboratory air voids content between 3.0 to 5.0%
- voids filled with binder (VFB) above 75% (indicative only)
- exclude Marshall stability (MS) and flow (MF) from testing
- particle loss [2] < 8%
- wheel tracking [3]< 2mm
- resilient modulus [4] > 1800 MPa.

In order to minimise variability during production, no recycled asphalt pavement (RAP) should be added to the asphalt mix.

2.5. Binder development and selection

Based on past experiences it was clear that the asphalt mix volumetric properties do not guarantee high in-situ performance and the selection of the binder cannot be done in a conventional way. For this particular application the binder was developed by benchmarking of the rheological properties of different bitumen [5] and polymer modified bitumen (PMB) [6] widely available on the Australian market. The binder properties, summaries in Table 1, were assessed by means of conventional test methods and the dynamic shear rheometer (DSR). The complex modulus and the phase angle of the different binders, related to race car loading frequency and sub-tropical pavement temperatures, were considered as key input parameters.

Table 1. Properties of the NRB developed for the NRM

Property	Test methods	Unit	Limits
Viscosity 165°C	AGPT/T111 [7]	Pa.s	Max. 0.60
Torsional recovery	AGPT/T122 [8]	%	Min. 6
Softening point	AGPT/T131 [9]	°C	Min. 62
Loss on heating	AGPT/T103 [10]	%	Max. 0.6
Segregation	AGPT/T108 [11]	%	Max. 8
Complex modulus (G*) @ 60°C, 10 rad/s (DSR)	ASSHTO T315-12 [12]	Pa	Min. 10 000
Phase angle (δ), @ 60°C, 10 rad/s (DSR)		°	Max. 70

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 [13, 14]. It was found that a suitable binder for V8 racing conditions in the Australian climate should have G* > 10 000 Pa and δ < 70°, when tested in the DSR at 60°C, 10 rad/s.

Experience indicates that race circuits start to disintegrate at high ambient temperature and after a certain number of laps, when the hot tyres transfer more heat to the asphalt layer. Once the surface starts disintegrating the asphalt layer rapidly deteriorates. According to the above the most important properties for V8 racing conditions are the stiffness (G*) and the elastic behaviour (δ) at 60°C.

Other available binder types according to AGPT/T190 were also tested for benchmarking; an A35P (plastomeric modification) and A10E (elastomeric modification).

DSR tests were performed according to the AASHTO test method [12]. Based on past experiences 5% strain was used in the temperature-frequency sweep, which was performed between 20 and 70°C at 5°C increments as follows:

- 15 different frequency values between 0.1–0.1585–0.2512–0.3981–0.631–1.0–1.585–2.512–3.981–6.31–10.0–15.85–25.12–39.81–62.83 rad/s
- for temperatures between 50–70°C
  - larger diameter sample of 25 mm
  - gap (i.e. sample thickness) 1.0 mm; trimming gap at 1.05 mm to achieve 1.0 mm gap
- for temperatures between 20–50°C
  - small diameter sample of 8 mm
  - gap (i.e. sample thickness) 2.0 mm; trimming gap at 2.1 mm to achieve 2.0 mm gap.

The DSR temperature-frequency sweep data was used for obtaining the G* and δ values at 60°C and 10 rad/s and 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. It had already been shown in multiple studies that the DSR test provides very good repeatability [15].

In Australia, plain binders are specified according to AS2008, where the primary property is the viscosity at 60°C. PMBs are specified in line with AGPT/T190 with the main properties being viscosity at 165°C, softening point and torsional recovery. For a single point assessment the test results of G* (complex modulus) and δ (phase angle) for 60°C are shown in Table 2; the master curves are summarised in Figure 2. The graphs also include a typical test result for a conforming Class 170 (C170) binder according to AS2008, an EVA modified binder (A35P) and an SBS modified binder (A10E) according to AGPT/T190.

A general correlation between G*/sinδ and rutting susceptibility is that a binder with a higher G*/sinδ will produce an asphalt mix with a lower rutting susceptibility [14]. Considering the values in Table 2 the newly developed binder shows extremely high G*/sinδ value, therefore its susceptibility to rutting is extremely low.

Table 2. General and performance based properties of various binders

Binder type	**Viscosity @ 165°C**	**Torsional recovery @ 25°C, 30s (%)**	**Softening point (°C)**	**Viscosity @ 60°C, 1 rad/s**	**Complex modulus (G*) @ 60°C, 10rad/s**	**Phase angle (δ) @ 60°C, 10rad/s**	**G*/sin(δ)**
Test method	AGPT/T111	AGPT/T122	AGPT/T131	AASHTO T 315–12			
C170	N/A	N/A	N/A	176	1693	87	1.7
A35P	0.395	21	66.5	1109	6129	69	6.6
A10E	0.587	76	98.0	3243	9603	47	13.1
NRB	0.558	12	72.0	8329	36580	60	42.2

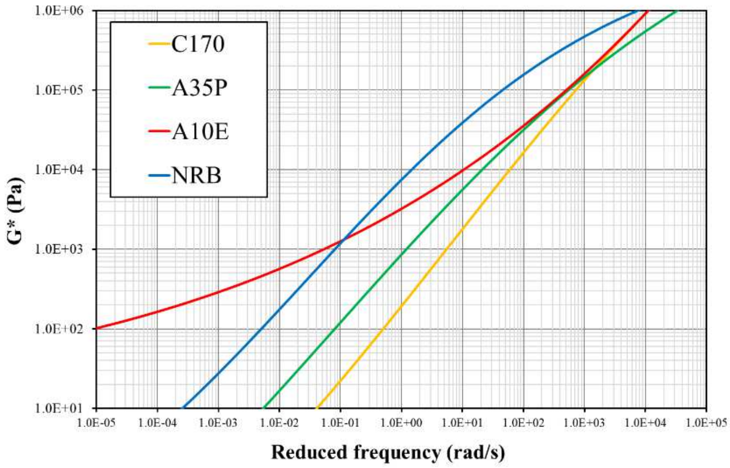

Figure 2: Complex modulus master curves of various binders

Based on the above information, an asphalt mix for V8 conditions requires a binder which has carefully balanced performance properties to provide stiffness and elasticity that will withstand the shear forces.

2.6. Asphalt particle loss test

In order to meet the design objectives it was decided to use the Asphalt particle loss test according to Austroads test method AGPT/T236 [2], also known as the Cantabro test or Los Angeles (LA) abrasion test. This test method is primarily used for the assessment of open graded asphalt, but the test itself is designed to subject the test specimen to harsh conditions to assess the cohesion of the mix. Thus, the asphalt particle loss test was considered a suitable test method for developing a benchmarking tool for the assessment of the various versions of the design mix by cross-checking long term in situ and laboratory performance.

Figure 3 shows the particle loss test results for the asphalt mix sampled from locations where the surface previously showed distress (Turn 1 to Chicane) and the test results for the newly developed asphalt mix. In order to assess the risk of any under-compaction (air voids above 6%) in the field, the samples were compacted to target air voids of 3-6-9% and subjected to the particle loss test. The corresponding air voids of the samples are also shown on the secondary axis of Figure 3.

It can be seen in Figure 3 that high in situ air voids with the old asphalt surfacing is generally linked with high levels of particle loss. The newly developed asphalt mix however shows low levels of particle loss at low air voids (<6%) and the risk of disintegration remains fairly low even at high air voids (>6%). In situ air voids above 6% however should be avoided.

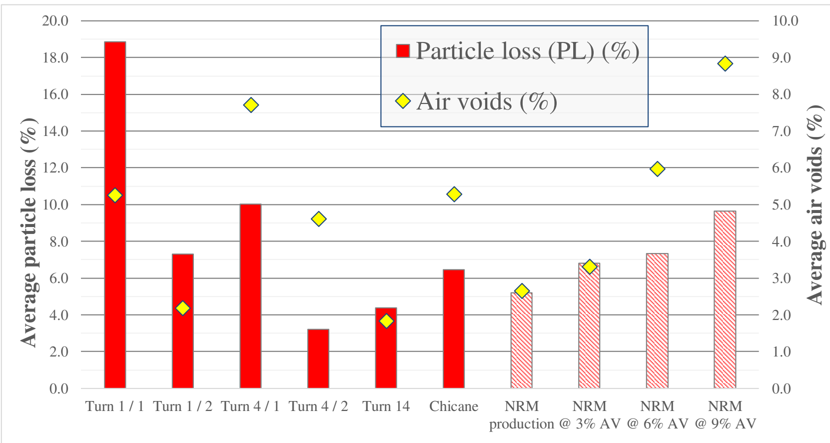

Figure 3: Particle loss test results

2.7. Wheel-tracking test

Wheel-tracing tests according to AGPT/T231 [3] were completed on the new race mix. In order to get more confidence in the design, the test was run to 60,000 passes, which is a loading six times higher than normally required for wheel-tracking test (10,000 passes). For benchmarking purposes AC20H(600), a standard base layer asphalt mix test result is provided and the results are summarised in Figure 4; wheel tracking depth for the new race mix are considered very low for such a high level of loading [1].

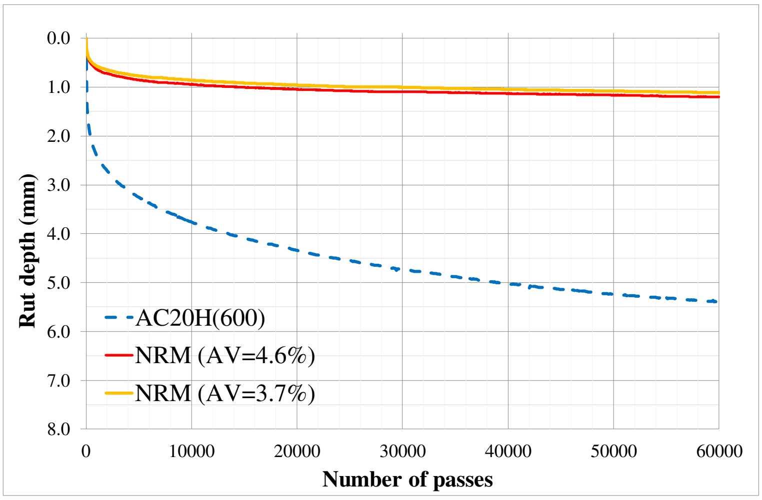

Figure 4: Wheel-tracking charts of the new race mix compared with a benchmarking mix

2.8. Resilient modulus test

As part of the validation process resilient modulus testing [4] was completed on a series of laboratory made pats. The samples were tested for resilient modulus at 25 and 32°C and the results are summarised in Table 3. The standard test condition is 25°C; however, pavements are designed and assessed at a weighted mean annual pavement temperature (wMAPT) in Brisbane at 32°C. The standard test conditions require that samples are prepared at an air voids content of 5%±0.5%. It was found that despite the high air voids content, required by the test method, the asphalt mix showed a high resilient modulus value.

Table 3. Resilient modulus results for the new race mix

Sample	Air voids (%)	Resilient modulus @ 25°C (MPa)	Resilient modulus @ 32°C (MPa)
1	5.4	3786	2213
2	5.6	4021	2422
3	5.6	3904	2236
Average	5.5	3904	2290

3. PRODUCTION, WORKMANSHIP AND PAVING

Following the development of a suitable asphalt mix, the first production and placement trial was carried out on a private race track, where performance was monitored under simulated race conditions. With performance parameters set and input from the race car drivers incorporated, monitoring of the trial section concluded that the asphalt mix was suited for the Surfers Paradise street circuit.
Production control, paving and workmanship are considered essential with such a development [16]; this includes a wide range of production and process controls which can be summarised in short as follow:

- Every member of the production and paving crew should be informed of the objectives of the works and ample time should be provided for planning of the entire process.
- The mix can be produced with close to the design properties when a suitable statistical production control is implemented.
- Vibratory steel wheeled rollers seem to be adequate for breakdown compaction, multi-tyres rollers for additional compaction and steel wheeled rollers for the back rolling. The rollers have to be kept close to the paver. This is normally possible despite the high binder content of the asphalt mix. Multi-tyres rollers normally cannot enter the mat before the mat cools below 120-130°C due to pick up.
- Despite the relatively unworkable nature of the mix, good compaction can be achieved when keeping the temperatures at the correct levels and utilising correct and appropriate rolling sequences.
- Thermal imaging cameras aid with measuring surface temperatures, which are approximately 20°C lower than in-mat temperatures. In mat temperatures can be recorded using T-type thermocouples and a four channel Testo data logger.

- The performance of the binder is considered one of the most critical factors. Therefore the binder collected during the trial and at different stages of the resurfacing works was monitored and tested using the DSR.
- Back raking and broadcasting should be minimised to avoid segregation of the asphalt mix.

Figure 5 shows an example of a carefully executed production and paving process.

Figure 5: Finished surface (pit lane)

4. SUMMARY

The asphalt mix for race conditions, by definition, should be durable and stable and capable of withstanding extreme horizontal shear forces. Good support is essential for the compaction of an asphalt mix for V8 race conditions. Therefore, a base layer (preferably asphalt) with good bearing capacity should be laid below such a mix as it cannot be compacted to the required high standards on unbound granular pavement. The bitumen selection for this particular application was based on the benchmarking of the rheological properties of different bitumen types by means of the dynamic shear rheometer (DSR). The complex modulus and the phase angle of the different binders related to race car loading frequency and sub-tropical pavement temperatures were considered key input parameters.

During one single motorsport event more than 12 000 laps are made in as short a time as three days. This is considered significant loading on an asphalt surface. In the short time of the V8 Supercars Main Race alone, the number of laps on average equate to one pass every 3 seconds. There is no other traffic environment in which there would be a combination of such high stress and frequency. Airport runway pavements are generally considered high stress areas. However, in comparison, the frequency of load repetitions on an airfield pavement is in minutes rather than seconds. Due to the nature of bitumen and asphalt the loading frequency cannot be underestimated.

The new mix design methodology has proven it can withstand extreme racing conditions while extending pavement life and reducing maintenance costs. The design approach delivered a high-performance asphalt pavement that enhances pavement lifecycles, increases time between maintenance activities and reduces consumption of virgin materials. Post construction laboratory tests indicated that the objectives of this complex task were met. These findings have been validated by the successful conclusion of multiple racing events without any signs of distress.

REFERENCES

[1] Austroads 2014, Guide to pavement technology: part 4b: asphalt, AGPT04B-14, Austroads, Sydney, NSW.
[2] AGPT-T236, Asphalt particle loss.
[3] AGPT-T231, Deformation resistance of asphalt mixtures by the wheel tracking test.
[4] AS/NZS 2891.13.1-2013, Determination of the resilient modulus of asphalt: indirect tensile method.
[5] AS 2008, Bitumen for pavements
[6] AGPT-T190, Specification framework for polymer modified binders.
[7] AGPT/T111, Handling viscosity of polymer modified binders, (Brookfield thermosel).
[8] AGPT/T122, Torsional recovery of polymer modified binders.
[9] AGPT/T131, Softening point of polymer modified binders.
[10] AGPT/T103, Pre-treatment and loss on heating of bitumen, multigrade and polymer modified binders (rolling thin film oven (RTFO) test).

[11] AGPT/T108, Segregation of polymer modified binders.
[12] 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.
[13] Asphalt Institute 2011, MS-26 asphalt binder handbook, Asphalt Institute, Lexington, Kentucky, USA.
[14] Stuart, KD & Izzo, RP 1995, 'Correlation of Superpave G*/Sin with rutting susceptibility for laboratory mixtures', Transportation Research Record, no. 1492, pp. 176-83.
[15] Austroads 2016, Maximising the use of reclaimed asphalt pavement in asphalt mix design: field validation, AP-R517-16, Austroads, Sydney, NSW.
[16] S. Bohm, M. Drees, G. Faust, R. Hart, M. Limbach, Erneuerung der Schnellfahrbahn im Opel-Testzentrum Dudenhofen 2012, Strasse und Autobahn, 11/2014.

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