Creating opportunity for increasing the use of Off-the-Road (OTR) tyres derived crumb rubber in roading applications

Report

This report is also available at the Tyre Stewardship Australia website.

Summary

The report includes information about the recent project funded by Tyre Stewardship Australia (TSA) in collaboration with Sunshine Coast Council and Boral Asphalt. The project aimed to undertake construction projects in the Sunshine Coast to characterise the constructability and performance of Crumb Rubber Gap Graded (GGA) mixes using crumb rubber manufactured from 100% Off the Road (OTR) tyres.

OTR tyres are manufactured for mining, agriculture, aviation, manufacturing, and construction industries. These tyres are designed for natural terrains, harsher environments, and larger load requirements. The sizes differ for each machinery according to its purpose and day-to-day operational demands, varying from a forklift tyre with a rim of less than 20cm, to mining dump truck tyres with a rim size of nearly two metres (63 inch) that weigh up to five tonnes.

The OTR tyres for the project were sourced internally by Boral from their West Burleigh Quarry site, which produces high-quality greywacke aggregates for asphalt, concrete, and road base supply in the region. The quarry is located close to the crumb rubber manufacturer, Carroll Engineering, which produced the #30 Mesh Crumb rubber for the demonstration project.

The OTR tyres were sourced from the following equipment in use at the Boral West Burleigh Quarry:

- Front end loader: Caterpillar 980H Sales Loader [Tyre type 24.00 R35]
- Quarry Haul / Dump Truck: Komatsu 405 [Tyre type 29.5 R25]

The collection and processing of Boral's OTR tyres from West Burleigh Quarry was carried out by Carroll Engineering. Approximately two-thirds of an OTR tyre is recovered, equating to approximately 400kg of crumb rubber per tyre. Ten tonnes of OTR Crumb Rubber (CR) were manufactured and supplied to Puma Bitumen for blending into bitumen. The equivalent of 25 large earthmover tyres was used in this demonstration.

Parties involved in the project were:

- Puma: crumb rubber bitumen supplier
- Carrol Engineering: crumb rubber manufacturer
- Boral & Allen's Asphalt
- RMIT University
- Australian flexible Pavement Association (AfPA)

The demonstration project will generate knowledge about using OTR-derived crumb rubber, fostering a more sustainable waste-to-resource approach.

The project's findings will inform future policies and specifications around the use of crumb rubber asphalt and clarify the life cycle benefits of using crumb rubber asphalt compared to conventional dense graded asphalt, with a particular focus on the needs of local council roads.

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Introduction

Crumb Rubber technology is well known in Australia and has already been widely adopted for spray sealing applications. Crumb rubber modified binders (CRMB) are manufactured by adding processed tyres to a conventional bitumen to produce a modified bitumen. The addition of crumb rubber to bitumen has several reported benefits on the performance of the pavement, with many studies showing comparable properties to polymer-modified bitumen (i.e. SBS).

Crumb rubber increases the elasticity of the virgin binder by improving its torsional/elastic recovery, enhances the high-temperature behaviour of the binder and improves the long-term ageing resistance, especially against the UV radiation from the sun due to the additives used during the manufacturing process of vehicle tyres. Therefore, using the rubber from end-of-life tyres as bitumen modifiers represents a high-value recycling opportunity.

Traditionally, truck and passenger car tyres (or a blend) have been used to manufacture crumb rubber bitumen for asphalt and sprayed seals. Although currently, some tyre recyclers in Queensland are using OTR tyres blended with other tyres to manufacture crumb rubber (CR), there is limited knowledge on the composition of CR from Off the Road tyres, its impact on the properties of the crumb rubber modified bitumen and the final performance of the asphalt mixes.

The main objectives of the project are to assess whether the use of crumb rubber derived from OTR tyres can be interchanged with common crumb rubber in bitumen blends and asphalt mixes and to assess the constructability of asphalt mixes.

The Australian flexible Pavement Association (AfPA) is the peak body representing the flexible pavement industry in Australia. Through collaborations and partnerships, AfPA has introduced and implemented new technologies in Australia and created national model specifications to guide asset owners in creating technical specifications. AfPA produced the “Crumb rubber modified open-graded and gap graded asphalt pilot specification” document that road authorities have used as a reference to develop their specifications.

AfPA, in collaboration with the partners listed below, has coordinated the activities and monitored the project through peer review meetings held every two months with the primary contact from TSA.

Parties involved:

- Sunshine Coast Council – asset owner
- Puma Bitumen – bitumen supplier
- Carrol Engineering – crumb rubber manufacturer
- Boral – technical development and coordination of the trial
- Allen’s Asphalt – operational delivery
- RMIT University – independent testing

1. Project Description

This project aims to assess whether the use of crumb rubber derived from 100% OTR tyres can be interchanged with common crumb rubber in bitumen blends and to undertake construction projects in Sunshine Coast (QLD) to characterise the constructability of CR asphalt mixes using OTR tyres derived crumb rubber.

The OTR tyres were recovered from Boral quarry operations (24.00 R35 tyre from Caterpillar 980H sales loader and 29.5 R25 tyre from Komatsu 405 dump truck) and processed into crumb rubber at the Carrol Engineering manufacturing plant. The crumb rubber modified bitumen was manufactured by Puma Bitumen.

Discussions with the local government involved in the project indicated that 75% of their network includes residential roads, and the primary failure mode observed is oxidisation. Therefore, using crumb rubber can prolong the life of these pavements due to their anti-oxidisation properties.

Although the current specifications (TMR PSTS112, AfPA GGA OGA model specification) do not preclude the use of OTR tyres to manufacture crumb rubber, there is limited data to show the effect of this source of rubber in the manufacturing of CRM bitumen and asphalt mixes. Additionally, there is no specification on using crumb rubber asphalt mixes for local government applications.

The outcome of the project will provide more information about the OTR-derived crumb rubber and will also assess the CR asphalt mixes tailored to the local government resurfacing application.

The following deliverables are expected upon successful completion of this project:

- Increased knowledge about the characteristics and impact on binder performance of crumb rubber from OTR tyres
- Contribution to the development of local government specifications.

2. Other-than-truck Tyres Crumb Rubber Asphalt Demonstration Trial

Boral is currently involved in an asphalt supply and lay contract through Allen's Asphalt for the Sunshine Coast Regional Council.

Previously, in 2021, Boral Asphalt was awarded the first pilot project in QLD for Gap Graded Crumb Rubber Modified Asphalt for the QLD Department of Transport and Main Roads. As part of this first pilot project, a manufacturing and placement trial, requested by TMR, was conducted at a site located in the Sunshine Coast Council network, which was due for re-surfacing.

Following this project and further engagement, the Sunshine Coast Council technical staff expressed an active interest in further sustainable initiatives that would increase the durability of their pavements. Particular focus was on CR asphalt and surfacing treatments for their network, which is particularly susceptible to oxidation and cracking-related failure mechanisms.

Upon understanding the proposed AfPA / TSA project targeted at the suitability/use of OTR tyres in asphalt, Boral expressed interest in participation and referenced Sunshine Coast Council as an interested stakeholder for potential participation.

2.1 Demonstration sites

The demonstration sites have been selected in collaboration with Sunshine Coast Council technical staff to demonstrate the use of alternative asphalt mixes with crumb rubber bitumen from 100% OTR tyres as a substitute to conventional dense graded asphalt in local government applications.

Three sites were identified as part of the project, and three different mix designs:

1. Gap Graded 10mm mix for the collector roads in accordance with the requirements of the recently updated PSTS112 TMR specification for application with OTR CRMB.

2. Gap Graded 7mm mix for the residential streets in accordance with Boral internal (proprietary) binder content, grading and volumetric compliance limits along with the application of all other PSTS112 specification requirements.

3. High Binder Content Gap Graded 7mm mix for rural residential streets in accordance with Boral internal (proprietary) binder content, grading and volumetric compliance limits along with the application of all other PSTS112 specification requirements.

Site #1 – Perlan Street Nambour – residential street (Fig.1)

Proposed Area = 1731 m² [Approx. 240 metres long x 7.2 metres wide – nominal 32.5mm depth].
Treatment A: 180 m² = Full surface plane, with C170 and 10mm cover aggregate seal. [25 metres length].
Treatment B: 1551 m² = Edge plane and overlay over the existing seal. [215 metres length].
Quantity and asphalt mix type
150.00 tonnes laid -> 7mm GGA7 OTR CRB mix [Boral internal proprietary mix specification].

Figure 1 - Site 1 before, during and after construction.

Site #2 – Railway Parade Glasshouse Mountains – collector road (Fig.2)

Proposed Area = 2918 m² [Approx. 389 metres long x 7.5 metres wide – nominal 35mm depth].
Treatment: 50 mm AC14-A15E mix over S25E seal treatment.

Quantity and asphalt mix type

242.00 tonnes laid -> 35mm GGA10 OTR CRB mix [TMR pilot specification PSTS112 – draft] placed over S25E seal treatment.

Figure 2 - Site 2 before, during and after construction

Site #3 – Spalls Road Diddillibah – rural residential street (Fig.3)

Proposed Area = 2798 m² [Approx. 553 metres long x average 5.1 metres wide – nominal 35mm depth].
Treatment A: 930 m² - 32.5mm overlay - Treatment B: 1868 m² - 25mm overlay.

Quantity and asphalt mix type

194.84 tonnes laid -> 25 mm GGA7 OTR CRB mix [Boral internal proprietary mix specification].

Figure 3 - Site 3 before, during and after construction

2.2 Crumb rubber and crumb rubber modified bitumen

Crumb rubber was manufactured in Queensland by Carroll Engineering.

The proposed scope for the OTR CR binder planned for use in the project was to be as close as practically achievable to the QLD DTMR PSTS112 specification adopted for selected pilot projects in SEQ over the previous 18 months.

A laboratory blended sample was prepared by Boral and assessed for compliance with the point of delivery parameters of the specification:

1. Torsional Recovery
2. Softening Point
3. Viscosity

The crumb rubber modified bitumen was manufactured by Puma in their Queensland facility. Crumb rubber bitumen tested at the Puma's laboratory was compliant with the requirements of PSTS 112 (Queensland Pilot specification for CRB).

2.3 Crumb rubber composition

RMIT University was engaged by the Australian Flexible Pavement Association (AfPA) to assess the chemical composition of the crumb rubber. Two crumb rubber samples named '30 Mesh' and '30 Mesh OTR' were collected and sent to RMIT University.

The '30 Mesh OTR' represented the CR derived from OTR tyres supplied by Boral Quarry; '30 Mesh' represented the CR from a blend of passenger tyres (PT) and truck tyres (TT) commonly manufactured by Carroll Engineering. The crumb rubber samples were assessed by thermogravimetric analysis (TGA): the sample was exposed to increasing temperatures from 30°C to 850°C, and the corresponding mass loss correlated to the degradation of volatiles, natural rubber, synthetic rubber and carbon black from the sample. The components of the samples were identified by analysing the rate of change of mass with respect to temperature.

As detailed in the test report in Appendix A, the results showed that the two samples differed slightly in the content of natural and synthetic rubber. The 30 Mesh OTR shows greater natural rubber content (approximately 3%) and less synthetic rubber (approximately 2.5%). Carbon black and filler content are also slightly different. However, no significant difference exists between the two sources of rubber.

The findings suggest their use can be interchanged in asphalt mixes and bitumen blends.

2.3.1 Crumb rubber modified binder assessment

As part of this demonstration project, a comparison and assessment against the A18R specification requirement included in the ATS 3110 was also planned. RMIT University was engaged by AfPA to run a series of binder tests on the OTR CR-modified binder. Pre-blended CR-modified binders were supplied by Boral Asphalt to RMIT University laboratories.

The samples were labelled C170 + 18%CR + 2% SAS. The original C170 bitumen was modified with 18% CR from OTR tyres by weight of total binder and 2% warm-mix asphalt additive. Table 1 presents a summary of the binder testing per ATS 3110.

Table 1 Summary of binder testing

Binder Property	Test Method	A18R req's (ATS 3110)	C170 + 18% CR + 2% SAS
Viscosity at 165 °C (Pa.s) max.	AS 2341.4	6.2	1.35
Torsional recovery at 25 °C, 30 s (%)	AGPT-T122	30-70	35
Softening point (°C)	AS 2341.18	62-80	70.7
Stress ratio at 10°C min.	AGPT/T125	TBR	1.34
Consistency 6% at 60 °C (Pa.s) min.	AGPT/T121	1,000	2,107.6
Segregation (%) max.	AGPT/T108	-8 to +8	25.6

The results from Table 1 show that all the binder properties for the crumb rubber modified bitumen satisfied the requirements of ATS 3110 for A18R, except for segregation. A significant amount of clumping was identified on the surface of the binder after 48 h of conditioning at 180 °C, as shown in Figure 4. It should be observed that segregation issues can be addressed by modifying the blending method and/or by adding compatibilisers. Additional operational measures associated with storage and handling of the binder along with careful planning/timing of delivery f works can minimize segregation during construction.

Figure 4 Clumping in the CR modified binder during the segregation test

Samples of CRMB were also analysed to assess photo-oxidative aging. The deterioration of roads is inevitable due to continuous exposure to environmental factors such as temperature, moisture, and sunlight radiation. These factors can alter the composition of bitumen, affecting its mechanical properties and resulting in pavement distress, specifically cracking.

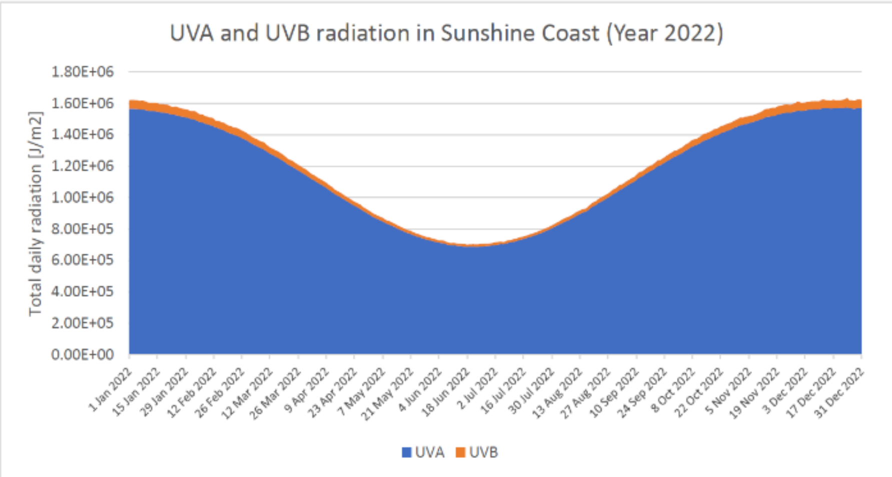
Heat and ultraviolet (UV) radiation have been identified as the main contributors to oxidative aging in bitumen. However, they do not cause the same damage, as the sensitivity of bitumen molecules to heat and UV varies significantly. Bitumen starts to age as soon as the asphalt mix is produced, transported, and paved on-site because these processes occur at elevated temperatures, inducing the thermal oxidation of bitumen molecules. Throughout its service life, a road undergoes continuous aging due to exposure to UV radiation from the sun, a process known as photooxidation. Over time, bitumen becomes more brittle and less resistant to cracking, resulting in the formation of cracks on the road surface.

The binder samples were analysed at RMIT University using a Suntest Atlas weathering chamber equipped with a xenon lamp (280 – 3000+ nm) and a daylight filter. A xenon lamp was chosen because it emits a distribution of UV radiation similar to the sun. The samples were exposed to UV radiation in the chamber, and their properties were measured before and after UV aging. Results were compared with those of conventional unmodified C320 bitumen to identify the increased resistance to photo-oxidative aging provided by the addition of crumb rubber.

The solar (UVA and UVB) radiation data collected daily in Sunshine Coast in 2022 by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) were used to calculate the total UV radiant exposure, considering a clear sky (i.e., worst-case scenario). Based on the total radiant exposure of 425 MJ/m2 and the irradiance (300-800 nm range) of the xenon lamp used in the weathering chamber, one year of outdoor exposure to sunlight in Sunshine Coast could be simulated by 69.3 days in the Suntest Atlas weathering chamber.

A summary of the total solar radiation for the Year 2022 in the Sunshine Coast is shown in Figure 5.

Figure 5 Annual solar radiation (UVA and UVB) in Sunshine Coast



A series of unmodified C320 bitumen samples were also exposed to the same UV radiation for comparison purposes, and both binders were tested using a dynamic shear rheometer to identify any changes occurring in the samples before and after UV ageing.

Figure 6 shows the CR-modified binder samples after 69.3 days of exposure to UV radiation.

Figure 6 Binder samples after UV exposure

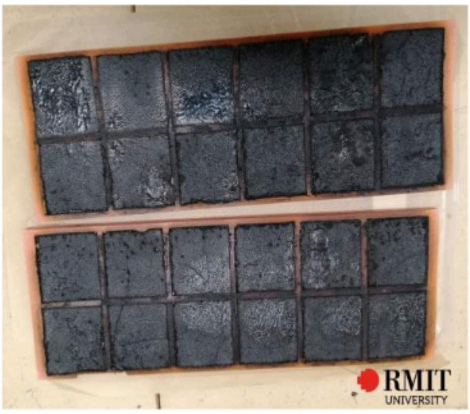


Figure 7 Conventional unmodified binder exposed to UV radiations

Results showed that the unmodified C320 was severely affected by photo-oxidative ageing (Fig. 7) to a much larger extent than the CR-modified binder. Particularly under visual assessment, a significant change in shape was observed, and the samples shrank during UV conditioning. Pinholes, localised embrittlement areas, and cracking were also observed. In comparison, CRMB samples (Fig. 6) did not exhibit the same level of shrinking, although scattered cracking was also present.

The study also examined changes in the properties of the binder. Overall, UV radiations increased the binder stiffness and decreased its viscous response associated with its capability to relax thermal stresses and cope with environmental damage, especially in the low-temperature domain. The CR in the binder seemed to retain its effectiveness even after UV aging. The CR-modified binder retained a more elastic response after aging. Particularly during warmer seasons, this aspect can positively affect the rutting resistance of the binder compared to unmodified bitumen.

Further testing (Glover Rowe parameter) showed that the ageing of the CRMB due to UV damage is significantly less than that of conventional bitumen, showing that the addition of CR slows down the deterioration of the base binder. The trend observed in the data analysis shows a reduction of UV damage of approximately 42% when crumb rubber is used in the bitumen as a modifier.

Less UV damage entails greater resistance to environmental cracking and, overall, longer road durability. This aspect is especially relevant for local council roads where most damage is caused by environmental factors (including UV radiation) rather than traffic loads.

A full detailed report is available on request.

2.4 Asphalt mix design

2.4.1 Selection of treatments and mix design

Boral formulated three CR asphalt mixes for the demonstration project tailored to the needs of the Sunshine Coast Regional Council with respect to suitable applications for collector roads, residential streets, and rural residential street applications and as an alternative to the conventional dense graded asphalt.

Accordingly, the following three mixed designs & compliance assessment frameworks were developed.

1. Gap Graded 10mm mix for the collector roads in accordance with the requirements of the PSTS112 TMR for application with OTR CRMB.
2. Gap Graded 7mm mix for the residential streets in accordance with Boral internal (proprietary) binder content, grading and volumetric compliance limits along with the application of all other PSTS112 specification requirements using OTR CRMB, production volumetric (air voids requirement) equivalent to local government specification requirements and targeting field impermeability.
3. High Binder Content Gap Graded 7mm mix for rural residential streets in accordance with Boral internal (proprietary) binder content, grading and volumetric compliance limits along with the application of all other PSTS112 specification requirements and targeting low in-situ voids content and high field impermeability.

2.4.2 Asphalt manufacturing

Given Boral's recent involvement in the first pilot project of 2021 with Gap Graded Crumb Rubber asphalt, the production teams were well prepared for the requirements necessary, from a production aspect, for this OTR CRMB demonstration project.

The OTR CRMB was deemed to have the same or very similar storage and handling characteristics as the standard CRMB used in pilot trials. Accordingly, careful planning and coordination of quantities for binder orders and delivery and storage times were considered. The storage stability of the binder meant that the product for this OTR demonstration was manufactured strictly on demand from Puma's Bulwer facility and transported to the Boral Asphalt plant at Caboolture (approx. 45 mins).

A minor delay at the binder terminal with one of the delivery tankers contributed to a minor change in the scope of site activities and breakdown for each of the three sites, given that the scope of trial site #1 involved direct comparison against the standard local government mix with Class 320 binder.

The manufacture and delivery of the CRMB product on demand potentially contributed to a non-conformance in the manufacturer (Puma Bitumen) point of release testing for viscosity @ 175° C. The outcome was abnormally high viscosity results, whilst all other parameters of both point of delivery and manufacturer release properties for the binder were fully conforming. Boral conducted extensive viscosity testing at the point of delivery (asphalt plant) with the Rion handheld viscometer, all conforming with the requirements of the specification. It is envisaged that this provides a logical reason or explanation for the anomaly: the timing of sampling/testing for viscosity at the binder terminal, which may have been conducted when a significant reaction called "viscosity spike" occurred. It is unknown at this stage. Nonetheless, it is considered unlikely to be directly related to the use of OTR in lieu of passenger/truck CR blends but rather related to the timing of sampling & testing, given the compliance demonstrated after 4 hours down the supply chain.

Other manufacturing considerations already well understood from previous works included:

1. The reduction in manufacturing temperatures to below 165°C aligns with the safety-related aspects of CRMB use that were adopted during the technology transfer and development and implementation of the pilot specification for QLD.
2. The reduction of production capability is associated with increased binder content and high-viscosity binder mix (i.e. the capacity of the existing bitumen pump to deliver volume).
3. Logistic (transport) considerations associated with the production of a "specialty mix." Specifically, the aim was to minimise the amount of production startups/shutdowns due to the nature of the mix, and accordingly, an additional level of coordination/planning was required with delivery vehicles to ensure success.

2.4.3 Asphalt placement

Asphalt placement has been identified as a key concern and consideration for this project, particularly the workability and aesthetic aspect of a high binder content crumb rubber modified mix being laid successfully in a residential street application.

Boral engaged heavily with other stakeholders, particularly the Sunshine Coast Regional Council, to ensure that the sites for this initial OTR demonstration were carefully selected and low-risk, especially considering the asphalt mix workability. Accordingly, the three sites selected for the OTR CRMB mixes all involved relatively straight paving runs in straight sequences with limited complexity (i.e., cul-de-sacs, high shear, and turnout style areas were omitted). This was a conservative risk-based approach to ensure paving crews were familiar with these mixes in lower trafficked but more intensive paving applications.

Strong support from Boral's technical team and discussion of all the OTR CR asphalt mixes and paving with the paving crew before work ensured overall successful outcomes.

Reduction in paving temperatures due to adding warm mix additives contributed to a visible reduction in fumes around paving equipment compared to conventional dense graded asphalt (DGA) and was widely acknowledged and commended by the crews. Typically, the paving temperature was around 140° C, and the compacting temperature was in the range of 110° – 125°C. No adverse feedback regarding smell or odour related to the CRMB was reported. Paving crews reported that the asphalt mix was workable thanks to the use of WMA. The gap-graded grading structure also provided a high level of consistency/homogeneity when paved in the field.

Compaction methodology was extensively toolboxed before the commencement of the works. Boral considered recent experience in compaction processed on previous demonstration works in terms of compaction methods, initially based on Caltrans literature and historical experience. The use of pneumatic tyres rolling as part of the process for the 7mm mixes in the residential and rural-residential roads was implemented to achieve as low as possible in-situ air voids and impermeability in the field. These were successfully demonstrated and achieved.

For the 3rd demonstration project site, there was a considerable delay to the commencement of paving due to the breakdown of the tack coating truck, leading to concern with the storage of this mix in delivery vehicles for approx. 4 hours. Further, there were concerns about the capability to place and pave the asphalt. However, when placement and paving commenced, no issues such as binder drain down of the asphalt mix in the trucks or "hang up" in truck bodies were experienced, and importantly, the paving, placement and compaction were not adversely affected.

This observation is very encouraging and can lead to an investigation of further temperature reductions with this type of mix. The behaviour of this mix is believed to be attributed to the suitability of the warm mix additive and the lubricating effect of high viscosity/high binder content mix, which retards drainage, is stable when paved, but also maintains a level of flexibility to allow an extended workability window.

2.5 Construction testing and monitoring

The in-situ air voids content of the asphalt compacted material plays a significant role in the overall quality and durability of the asphalt pavement. Pavements with excessively high or low air voids content may result in premature failures.

All in-situ compaction compliance testing conformed with the requirements of standard specifications (e.g. $\leqslant$ 7.0% in-situ air voids).

The OTR CRB 7mm mixes for the residential street applications were compacted to lower in-situ air void contents than the standard treatment of 10mm C320 mix.

The OTR GGA10 CRB for the collector road application had higher in-situ air voids than the benchmarked and standard treatment mix AC14-A15E. Pneumatic tyred rolling is to be incorporated into the updated construction methodology for collector roads to reduce in-situ voids and asphalt permeability.

2.5.1 Performance testing

The OTR CRMB asphalt mixes laid in residential streets showed reduced permeability and an increased cracking resistance when compared to the Dense Graded mixes.

Collector road application mixes showed increased permeability and inferior Hamburg WT results on the GGA10 OTR CRMB mix compared to the conventional AC14-A15E treatment. However, it is important to consider the variables associated with these two mixes: thickness difference of 35mm OTR CR mix vs 50mm for the AC14A15E mix and increased in-situ voids in OTR CR mix. Deformation resistance results for both mixes indicated equivalent performance and increased cracking resistance of the GGA10 OTR CR mix compared to the AC14-A15E mix. Fatigue resistance test results are inconclusive and may require further assessment.

The Ideal – CT (ASTM D8225-19) test has been performed on every mix. The test is a low cost and simple fracture test that determines an asphalt mix's fracture toughness by determining a Cracking Tolerance Index (CT Index). The CT Index is a function of the work of fracture and displacement required to grow a crack through a cylindrical asphalt sample in the test. As part of the study Ideal CT tests were run on different asphalt mix types. These results are shown in Table 2 below. As part of the work, samples were also aged using AASHTO R30 protocol which consists of aging compacted specimen in the oven at 85°C for five days. This is intended to simulate the long term aging in the field. The dataset is small and should not be interpreted as representative or typical for the mix types. The results however indicate a very clear ranking of the crack resistance in the test, with the polymer modified AC14 outperforming the C320 but the results for the gap graded rubber mixes, which are known for their crack resistance, are an order of magnitude higher than the dense graded BCC2 and AC14.

The results also show the effect of oxidative aging on fracture performance with the results for the AASHTO R30 samples consistently lower than the unaged specimens.

Table 2 Ideal CT test comparison

Ideal CT – CT index	Test Method	BCC2 asphalt mix (C320)	AC14 (A15E)	GGA10 (18%CR*)	GGA7 (18%CR*)	GGA7-UHB (18%CR*)
CT Index – Aged specimens	ASTM D8225	56	177	940	1950	4213
CT index – unaged specimens		125	197	1014	3407	7631

*18%CRB manufactured with OTR-derived crumb rubber

2.5.2 Emissions monitoring

The emission monitoring was requested to evaluate the airborne contaminant levels. Personal passive samplers for VOCs, aldehydes and ketone were worn by Lab Technicians at the T300 mobile plant located at Caboolture and paving crew workers at the Spalls Road, Diddillibah paving site. The results indicated that the level of airborne contaminants was below the Workplace Exposure Standard (WES) for any of the chemicals monitored. Not all compounds have a WES.

The airborne contaminant VOC testing results can be found in Appendix E.

3. Conclusion and Future Developments

3.1 Conclusion

This report was prepared to provide detailed information about the project funded by Tyre Stewardship Australia (TSA) in collaboration with Sunshine Coast Council.

The project aimed to assess whether crumb rubber derived from OTR tyres can be interchanged with common crumb rubber in bitumen blends and investigate the constructability of asphalt mixes using OTR-derived crumb rubber-modified bitumen.

Boral sourced the end-of-life OTR tyres from their West Burleigh Quarry site, located close to the crumb rubber manufacturer Carroll Engineering, who collected and processed the tyres to manufacture #30 Mesh OTR CR. The crumb rubber was used by Puma Bitumen to manufacture the crumb rubber modified bitumen for the demonstration project. Over 7,000 sqm were paved using 10,000kg of OTR-derived crumb rubber (equivalent to 25 large earthmover tyres).

RMIT University was engaged by the AfPA to assess the crumb rubber chemical composition and to run a series of binder tests on the OTR CR-modified binder per Austroads Technical Specification ATS 3110.

The thermogravimetric analysis used to assess the crumb rubber composition identified approximately 3% more natural crumb rubber and less synthetic rubber in the 30 Mesh OTR sample compared to the standard 30 Mesh commonly manufactured by Carrol Engineering. Carbon black and filler content are also slightly different, suggesting their use can be interchanged when used in bitumen blends.

The testing undertaken on the binder samples indicated that all the binder properties for the crumb rubber modified bitumen satisfied the requirements of ATS 3110 for A18R, except for segregation.

Conventional C320 bitumen and CRMB were also analysed using a Suntest Atlas weathering chamber equipped with a xenon lamp to assess the photo-oxidative ageing. Based on the solar (UVA and UVB) radiation data collected daily in Sunshine Coast in 2022, one year of outdoor exposure to sunlight was simulated by exposing bitumen samples in the weathering chamber for 69.3 days. Results showed that the unmodified C320 was severely affected by photo-oxidative ageing to a much larger extent compared to the CR-modified binder. Data showed a reduction of UV damage of approximately 42% when crumb rubber is used in the bitumen as a modifier.

Three different asphalt mixes were used for the three sites identified by the Council and representative of the types of roads in the council network (collector road, residential street, and residential, rural street). The CR asphalt mixes were tailored to different roads to provide an alternative to conventional dense-graded asphalt.

The asphalt mixes laid at around 140° and compacted at 110 – 125°C, had no adverse feedback regarding smell or odour.

Apart from a non-conformance in the testing for viscosity @ 175°C, likely due to the timing of the sampling and testing, all in-situ compaction compliance testing were conforming with the requirements of standard specifications. Boral undertook performance testing at their laboratory, where they found improved cracking resistance for the crumb rubber mixes.

Overall, the project successfully demonstrated that crumb rubber derived from OTR tyres can be interchanged with common crumb rubber in bitumen blends and used for the manufacture and placement of asphalt mixtures without the need for significant adjustments. Additionally, less UV damage demonstrated by the CRMB entails greater resistance to environmental cracking and, overall, longer road durability. This aspect is especially relevant for local council roads where most damage is caused by environmental factors (including UV radiation) rather than traffic loads.

3.2 Future developments

The project provided an opportunity to demonstrate that crumb rubber derived from OTR tyres can be interchanged with common crumb rubber in bitumen blends and confirmed the industry's readiness and capability to manufacture and pave CR asphalt mixes.

The project, an example of a circular economy approach and industry collaboration, demonstrated a viable solution to recycling end-of-life OTR tyres essential for the transition of society towards a more sustainable future.

It is recommended to engage local governments to share the learnings and to support further demonstration projects to increase the knowledge and expertise and expand the use of end-of-life tyres.

Appendix A

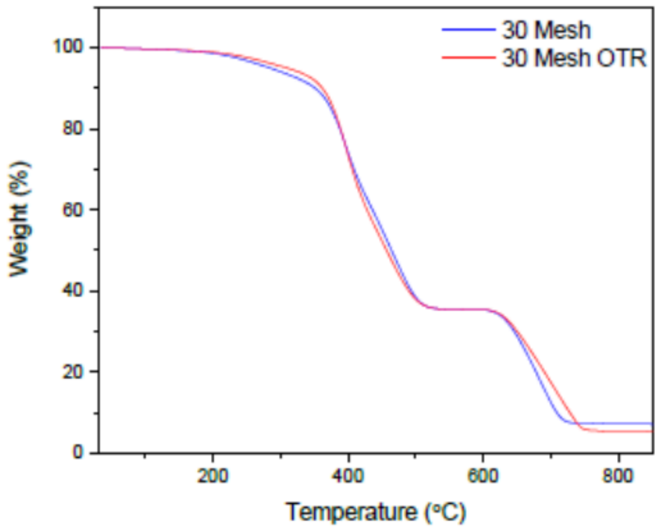
RMIT UNIVERSITY

TEST REPORT

The following test report highlights the composition of two samples of crumb rubber as received from Boral through AfPA. Crumb rubber was manufactured in Queensland by Carroll Engineering. The two samples received were named '30 Mesh' and '30 mesh OTR'.

Product(s)	30 Mesh	30 Mesh OTR
Photo of the samples		
		
Date of testing	24.05.23	
Test	Thermogravimetric analysis The composition of the samples was assessed by thermogravimetric analysis (TGA). The sample was exposed to raising temperature from 30 °C to 850 °C and the corresponding mass loss was correlated to the degradation of volatiles, natural rubber, synthetic rubber and carbon black from the sample. Ashes are made of inorganic compounds whose degradation temperature is higher than 850 °C. The mass loss is plotted against the temperature in the graph below. The unique components of the crumb rubber samples were identified by analysing the derivative thermogravimetric (DTG) curve, which is a plot of the rate of change of mass with respect to time or temperature.	

Results



Compound(s)	Fraction of compound(s) (%)	
	30 Mesh	30 Mesh OTR
Volatiles	12.9	12.3
Natural rubber	26	29.2
Synthetic rubber	25.9	23.3
Carbon black	27.9	29.8
Ashes	7.3	5.4
Total	100	100

Conclusions

The two samples provided differ slightly for the content of natural and synthetic rubber. 30 Mesh OTR shows greater natural rubber content (approximately 3%) and less synthetic rubber (approximately 2.5%). Carbon black and filler content are also slightly different, however, no significant different exists between the two sources of rubber. This can suggest their use can be interchanged when used in asphalt mixes and bitumen blends.

Appendix B

Puma Energy (Australia) Bitumen Pty Ltd

Bitumen

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Laboratory Test Report

Product Name	: CR OGA/GGA	Report Number	: 23/23096
Product Grade	: CR OGA/GGA	Date Reported	: 21-Apr-2023
Batch Number	: **23-6090**	Testing Laboratory	: Bulwer Laboratory
Sample Number	: 48380	Specification Quoted	: PSTS112
Sample Date	: 17-Apr-2023 4:55	Customer / Originator	: Puma Bitumen Bulwer Island Terminal 392 Tingira Street Pinkenba Queensland 4008
Sampled From	: BL406		
Sample Remarks	: B23P04070		

SAMPLE RESULTS

Analysis	Method	Units	Results	Specification Limits Min	Max
Softening Point of PMB					
Softening Point Medium	AG:PT/T131	-	Water		
Softening Point	AG:PT/T131	°C	68.5	55.0	
Torsional Recovery @ 25°C					
Torsional Recovery @ 25°C, 30 secs	ATM 122	%	51		
Brookfield Viscosity @ 175°C					
Brookfield Viscometer Model No.	ATM 111	-	LVDV2T		
Handling Viscosity @ 175°C	ATM 111	Pa s	3.06	1.5	4.0
Spindle Model No.	ATM 111	-	SC4-29		
Rotational Speed	ATM 111	rpm	20		
Shear Rate	ATM 111	Hz	5		
Penetration at 4°C					
Penetration @ 4°C (200g, 60s)	AS 2341.12	pu	34	15	
Resilience at 25°C					
Resilience @ 25°C	ASTM D5329	%	42	20	
Penetration at 25°C					
Penetration @ 25°C (100g, 5s)	AS 2341.12	pu	43		

SAMPLE COMMENTS

All tests have been performed in accordance with the latest revision of the test methods indicated. This report relates specifically to the sample as received.
All testing was performed between the sample date and date reported.
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George Mondon
(Approved Signatory)

NATA

Accredited for compliance with ISO/IEC 17025 - Testing
NATA Accreditation No. 19832; Site No. 23821

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Laboratory Test Report

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Sampled From	: BL406		
Sample Remarks	: B23P04070		

SAMPLE RESULTS

Analysis	Method	Units	Results	Specification Limits Min	Specification Limits Max

Analysis was performed by Puma Bitumen Technical Centre Australia. NATA Accredited Laboratory No. 19832. * NATA Accreditation does not cover the performance of the Penetration @ 4 deg C & Resilience @ 25 deg C.

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Laboratory Test Report

Product Name	: CR OGA/GGA	Report Number	: 23/23095
Product Grade	: CR OGA/GGA	Date Reported	: 21-Apr-2023
Batch Number	: **23-6091**	Testing Laboratory	: Bulwer Laboratory
Sample Number	: 48391	Specification Quoted	: PSTS112
Sample Date	: 17-Apr-2023 12:16	Customer / Originator	: Puma Bitumen Bulwer Island Terminal 392 Tingira Street Pinkenba Queensland 4008
Sampled From	: BL406		
Sample Remarks	: B23P04071		

SAMPLE RESULTS

Analysis	Method	Units	Results		Specification Limits Min	Max
Softening Point of PMB						
Softening Point Medium	AG:PT/T131	-	Water			
Softening Point	AG:PT/T131	°C	70.0		55.0	
Torsional Recovery @ 25°C						
Torsional Recovery @ 25°C, 30 secs	ATM 122	%	51			
Brookfield Viscosity @ 175°C						
Brookfield Viscometer Model No.	ATM 111	-	LVDV2T			
Handling Viscosity @ 175°C	ATM 111	Pa s	4.73	*	1.5	4.0
Spindle Model No.	ATM 111	-	SC4-29			
Rotational Speed	ATM 111	rpm	10			
Shear Rate	ATM 111	Hz	3			
Penetration at 4°C						
Penetration @ 4°C (200g, 60s)	AS 2341.12	pu	29		15	
Resilience at 25°C						
Resilience @ 25°C	ASTM D5329	%	51		20	
Penetration at 25°C						
Penetration @ 25°C (100g, 5s)	AS 2341.12	pu	38			

* Result is out of Specification

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Laboratory Test Report

Product Name	: CR OGA/GGA	Report Number	: 23/23095
Product Grade	: CR OGA/GGA	Date Reported	: 21-Apr-2023
Batch Number	: **23-6091**	Testing Laboratory	: Bulwer Laboratory
Sample Number	: 48391	Specification Quoted	: PSTS112
Sample Date	: 17-Apr-2023 12:16	Customer / Originator	: Puma Bitumen Bulwer Island Terminal 392 Tingira Street Pinkenba Queensland 4008
Sampled From	: BL406		
Sample Remarks	: B23P04071		

SAMPLE RESULTS

Analysis	Method	Units	Results	Specification Limits Min	Max

SAMPLE COMMENTS

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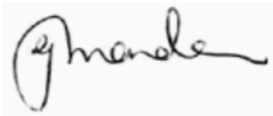

George Mondon
(Approved Signatory)

Analysis was performed by Puma Bitumen Technical Centre Australia. NATA Accredited Laboratory No. 19832. * NATA Accreditation does not cover the performance of the Penetration @ 4 deg C & Resilience @ 25 deg C.

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Laboratory Test Report

Product Name	: CR OGA/GGA	Report Number	: 23/23094
Product Grade	: CR OGA/GGA	Date Reported	: 21-Apr-2023
Batch Number	: **23-6093**	Testing Laboratory	: Bulwer Laboratory
Sample Number	: 48395	Specification Quoted	: PSTS112
Sample Date	: 18-Apr-2023 4:36	Customer / Originator	: Puma Bitumen Bulwer Island Terminal 392 Tingira Street Pinkenba Queensland 4008
Sampled From	: BL406		
Sample Remarks	: B23P04078		

SAMPLE RESULTS

Analysis	Method	Units	Results		Specification Limits Min	Max
Softening Point of PMB						
Softening Point Medium	AG:PT/T131	-	Water			
Softening Point	AG:PT/T131	°C	72.0		55.0	
Torsional Recovery @ 25°C						
Torsional Recovery @ 25°C, 30 secs	ATM 122	%	46			
Brookfield Viscosity @ 175°C						
Brookfield Viscometer Model No.	ATM 111	-	LVDV2T			
Handling Viscosity @ 175°C	ATM 111	Pa s	7.86	*	1.5	4.0
Spindle Model No.	ATM 111	-	SC4-29			
Rotational Speed	ATM 111	rpm	6			
Shear Rate	ATM 111	Hz	2			
Penetration at 4°C						
Penetration @ 4°C (200g, 60s)	AS 2341.12	pu	# 24		15	
Resilience at 25°C						
Resilience @ 25°C	ASTM D5329	%	# 53		20	
Penetration at 25°C						
Penetration @ 25°C (100g, 5s)	AS 2341.12	pu	32			

* Result is out of Specification

Accredited for compliance with ISO/IEC 17025 - Testing
NATA Accreditation No. 19832; Site No. 23821

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Laboratory Test Report

Product Name	: CR OGA/GGA	Report Number	: 23/23094
Product Grade	: CR OGA/GGA	Date Reported	: 21-Apr-2023
Batch Number	: **23-6093**	Testing Laboratory	: Bulwer Laboratory
Sample Number	: 48395	Specification Quoted	: PSTS112
Sample Date	: 18-Apr-2023 4:36	Customer / Originator	: Puma Bitumen Bulwer Island Terminal 392 Tingira Street Pinkenba Queensland 4008
Sampled From	: BL406		
Sample Remarks	: B23P04078		

SAMPLE RESULTS

Analysis	Method	Units	Results	Specification Limits Min	Max

SAMPLE COMMENTS

All tests have been performed in accordance with the latest revision of the test methods indicated. This report relates specifically to the sample as received.
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George Mondon
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Appendix C

BORAL Building something great

OTR CRB DEMONSTRATION PROJECT

Binder Point of Delivery Test Property Summary [OTR CRB]

Date	Time	Details	Torsional Recovery (%)	Softening Point (°c)	Viscosity (Pa.s) (Rion Handheld Viscometer)					
					175°c	170°c	165°c	155°c	150°c	145°c
			≥30	≥60	1.5 - 4.0	tbr	tbr	tbr	tbr	tbr
17-Apr-23	8:20am	Ex-Tanker	44	65		2.0	2.3	3.4	4.3	5.1
17-Apr-23	11:55am	In-Line ex T300	42	65	1.5		1.9	2.0	2.6	3.8
17-Apr-23	5:00pm	Ex-Tanker			3.8		4.3	4.9	6.0	6.8
18-Apr-23	11:15am	In-Line ex T300	40	70	2.2		2.5	3.4	4.3	4.9
18-Apr-23	1:45pm	Ex-Tanker					2.8	3.6	4.3	5.0
18-Apr-23	3:00pm	In-Line ex T300	37	68.5	1.9		2.4	3.4	4.4	5.2
20-Apr-23	8:30am	In-Line ex T300					2.7	2.8	4.1	5.6
20-Apr-23	1:00pm	In-Line ex T300					2.1	2.9	4.5	5.1

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Appendix D

BORAL Building something great

OTR CRB Demonstration Project

Asphalt Performance Testing Summary

Cracking Tolerance (Ideal-CT)	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
CT Index - Aged Specimens	ASTM D8225	56	177	940	1950	4213
CT Index - Unaged Specimens		125	197	1014	3407	7631
Test Report No.		-	-	-	-	-

Deformation Resistance	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
Final Tracking Depth (mm)	T231		1.2	1.2		
Tracking Rate (mm/kc)			0.05	0.07		
Test Report No.			ASP.105977	ASP105982		

Hamburg Wheel Tracking	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
Rut Depth - 50°c and 10,000 cycles	Q325		7.62	15.62		
No. Cycles Stripping Inflection Point			-	-		
Test Report No.			BA23-178	BA23-177		

Fatigue Characterisation	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
Initial Stiffness (Average)	T274	7325	4365	2338	2388	1800
Strain at 20°c, 10 Hz & 10^6 cycles		150	233	130	212	166
Test Report No.		ASP105979	ASP105978	tbc	ASP106002	tbc

---END OF DOCUMENT---

Appendix E

BORAL Building something great

OTR CRB DEMONSTRATION PROJECT

Asphalt Permeability Summary

Permeability Assessment 25mm nominal thickness	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
Permeability @ 6% air voids	Q304	11.9				
Permeability @ 7% air voids		59.7				
Permeability @ 8% air voids		299				
Permeability @ 9% air voids		1497				
Test Report No.		244-A04				

Permeability Assessment 35mm nominal thickness	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
Permeability @ 6% air voids	Q304	2.13		25.2		0.55
Permeability @ 7% air voids		5.34		55.2		3.15
Permeability @ 8% air voids		13.4		121		18
Permeability @ 9% air voids		33.5		265		103
Test Report No.		244-A05		251-A04		316-A02

Permeability Assessment 50mm nominal thickness	Test Method	BCC2 (C320)	AC14 (A15E)	GGA10 (OTR CRB)	GGA7 (OTR CRB)	GGA7-HB (OTR CRB)
Permeability @ 6% air voids	Q304		4.24			
Permeability @ 7% air voids			11.1			
Permeability @ 8% air voids			29.1			
Permeability @ 9% air voids			76.3			
Test Report No.			252-A04			

Note – Permeability Assessment unable to be obtained on mix GGA7 due to very low permeability obtained on specimens tested at 2-4% air voids range.

For mix GGA7-HB permeability testing conducted on in-situ field core samples at thickness ranging between 25-35mm.

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