AUSTRALIAN FLEXIBLE PAVEMENT ASSOCIATION

AUSTRALIAN ASPHALT PAVEMENT ASSOCIATION

Procure Recycled: Paving the Way Phase 2 initiative (Rubber)

Demonstration Projects Report Part 2

V1.1 May 2025

Executive Summary

The Southern Sydney Regional Organisation of Councils (SSROC), in collaboration with Tyre Stewardship Australia, engaged the Australian Flexible Pavement Association (AfPA) to provide technical assistance for the *Paving the Way – Phase 2 (Rubber)* project. The initiative aimed to promote the use of crumb rubber from end-of-life tyres in local government roads through a data-driven, evidence-based approach, fostering sustainable pavement solutions for SSROC councils.

This document is the second and final report of the project. It includes field construction details, contractor feedback, industry readiness, and field performance monitoring. All information presented was collected by SSROC and its consultants, then analysed by AfPA, which also provided technical assistance during the field demonstration projects. Further details on the project rationale, construction site descriptions, and the proposed data collection plan can be found in the first report previously submitted to SSROC.

Specifically, this report covers:

- The location and extent of each project across the various councils.
- The type of crumb rubber asphalt mix produced and applied, including rubber type and size, rubber content, aggregate gradation, bitumen content, field voids content and mix volumetrics (where available).
- Testing conducted on the crumb rubber asphalt, if applicable.
- Analysis of field monitoring data provided by Infrastructure Management Group (IMG).

IMG conducted three field monitoring activities over approximately one year: immediately after construction, after six months (December 2023 – January 2024), and after twelve months (June – July 2024). The data collected provided insights into the early evolution of pavement functional and structural performance under traffic loads and environmental conditions. Further monitoring by individual councils is recommended in the coming years.

Key Findings

Feedback and data collected from contractors at each construction site suggest the following:

- **Paving operations** generally adhered to the recommended guidelines (see the first project report), although minor deviations were observed in some councils. Note that job mix design, layer thickness, use of warm-mix technology, and other operational factors (e.g. compaction and production temperature) were determined through discussions between councils and contractors.
- **Data collection** on manufacturing and paving operations was generally thorough, but the level of detail varied across contractors.
- **Field monitoring after 12 months** indicated that most sections with crumb rubber modified asphalt exhibited less rutting and roughness compared to conventional asphalt mixes. However, no significant differences were observed in macrotexture.
- **Urban monitoring challenges:** Survey vehicles faced complexities in measuring pavement characteristics in urban environments due to fluctuating traffic conditions, parked vehicles, and localised factors, which occasionally impacted the consistency of monitoring results.

Recommendations

Councils are encouraged to continue regular visual inspections and collect additional performance data over time to track long-term pavement behaviour.

The findings from these demonstration projects within SSROC councils will contribute to national knowledge on using crumb rubber in local government roads, supporting a sustainable waste-to-resource approach without compromising asset durability.

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1 Introduction

In 2020, the Southern Sydney Regional Organisation of Councils (SSROC) launched the *Paving the Way* initiative to support and prioritise the use of recycled materials in procurement, aligning with both local and federal strategic policies. Following the successful implementation of the first phase - focused on recovering and using waste crushed glass as a natural sand replacement - SSROC initiated the second phase, which aimed to incorporate crumb rubber (CR) from end-of-life tyres into road construction.

Co-funded by Tyre Stewardship Australia (TSA), this phase of the project sought to assess supply and recycling processes, as well as the capability of the flexible pavement industry to integrate this recycled material into road-building applications, particularly in local government roads.

The Australian Flexible Pavement Association (AfPA) was engaged to provide technical support and guidance throughout the project's various stages. The project was structured in two parts:

1. **Industry Engagement & Information Gathering:** The first phase involved collecting data from asphalt contractors under the SSROC Sustainable Pavements contract through a Request for Information (RFI) process. AfPA and SSROC steering committee members analysed the responses, which informed the second phase of the project.
2. **Field Demonstration Projects:** This phase involved establishing multi-council demonstration project guidelines and conducting field trials at selected sites nominated by the councils.

The **first report**, released in 2023, detailed contractors' capabilities and experience with crumb rubber modified (CRM) asphalt in New South Wales. It also provided councils with technical recommendations for using CRM asphalt across various traffic conditions and road characteristics. This report served as the basis for the procurement phase, in which AfPA was not involved. Additionally, it outlined the methodology for the field monitoring phase, which was managed by SSROC.

This **second and final report** presents a comprehensive analysis of the ten demonstration projects undertaken at council-nominated sites. It includes:

- A description of each project site.
- Details on the CRM asphalt mix design used, including rubber source, content percentage, and production specifications.
- Information on contractors, plant operations, and site logistics.
- Testing results for both raw materials and the CRM asphalt (where available from the contractors).
- Findings from the 12-month field monitoring phase, assessing the pavement’s performance over time.

Overall, the variety of asphalt mix designs trialled and their performance assessments contribute to building a comprehensive database on the use of CR in asphalt for local government roads. This project provides councils with best-practice examples and viable alternatives to conventional road materials. The results will help identify optimal solutions tailored to each council’s needs, supporting the recycling of hard-to-dispose materials (such as end-of-life tyres), improving road sustainability and durability, and promoting whole-of-life cost-effectiveness.

2 Project Background

2.1 Project objectives

The multi-council demonstration project aimed to identify and address barriers and opportunities for increasing the use of crumb rubber (CR) from end-of-life vehicle tyres in asphalt roads. Its primary objective was to enhance awareness and confidence among councils in adopting CR asphalt.

The project focussed exclusively on the use of CR in wet-mix asphalt, where CR in fine powder form is added to bitumen before mixing with aggregate, effectively modifying the binder. Different CR content levels were trialled at various locations, ranging from low-content CR mixes (9% by binder weight) used for resurfacing local roads to high-content CR mixes (18% by binder weight) applied in deeper pavement interventions on collector, arterial, and regional roads.

2.2 Participating councils

A significant number of SSROC councils participated in the project, enabling the demonstration of various CR-based pavement treatments. Table 1 provides a complete list of the councils involved.

AfPA conducted individual consultations with relevant council staff and developed an online survey to gather key information for the development of technical guidelines. Detailed findings are presented in the first report, *Procure Recycled: Paving the Way – Phase 2 Initiative (Rubber) – Technical Analysis of Responses to SSROC RFI*. Further consultations were also conducted with additional stakeholders, including asphalt contractors and tyre recyclers, to confirm the feasibility of the proposed technical solutions at asphalt production and tyre recycling facilities.

The project guidelines were designed to enhance the sustainability of road infrastructure by incorporating CR from end-of-life tyres in a way that improves both durability and performance. Additionally, other secondary materials, such as Reclaimed Asphalt Pavement (RAP) and Recycled Crushed Glass (RCG), were incorporated into the recommended mix designs based on input from participating councils.

Table 1 List of councils involved in the SSROC project "Paving the Way – Part 2 (Rubber)"

#	Council
1	Bayside Council
2	Burwood Council
3	Woollahra Municipal council
4	Randwick City Council
5	Northern Beaches Council (outside of SSROC group of councils)
6	Sutherland Shire Council
7	Inner West Council
8	City of Sydney
9	City of Canada Bay
10	Canterbury-Bankstown City Council
11	Waverley Council
12	Georges River Council

Some of the main aspects of the SSROC demonstration project are:

- Eight SSROC councils incorporated recycled glass and/or RAP in their mixes. Generally, 2.5% RCG and 15% RAP are allowed in the asphalt wearing course, while 10% RCG and 30% RAP can be included in the asphalt base course.
- Most of the selected demonstration sites featured asphalt wearing courses exhibiting distresses related to structural deficiencies and/or ageing.
- Two sites had high Average Annual Daily Traffic (AADT) volumes ranging from 10,000 to 25,000 vehicles per day (vpd) - one being a regional road and the other a collector road with significant network usage.
- Five sites had medium AADT volumes between 6000 and 10,000 vpd.
- The remaining sites experienced low AADT volumes, with fewer than 6,000 vpd.

2.3 Participating contractors

Four contractors responded to the SSROC Request for Information (Table 2). Detailed information on each company's capabilities is provided in the first report, *Procure Recycled: Paving the Way – Phase 2 Initiative (Rubber) – Technical Analysis of Responses to SSROC RFI.*

Following an internal selection process conducted by SSROC, the following contractors were awarded the contract to carry out the demonstration project works:

- Bitupave Limited (Boral Asphalt)
- Fulton Hogan
- State Asphalt Services

Table 2 List of participating contractors and their respective projects

Contractor	Council
Bitupave (Boral Asphalt NSW)	Bayside Council Burwood Council City of Sydney Inner West Council Northern Beaches Council (Outside of SSROC group) Randwick City Council Sutherland Shire Council Woollahra Municipal council
Fulton Hogan	City of Canada Bay
State Asphalt Services	Canterbury Bankstown City Council Waverley Council Georges River Council

2.4 Monitoring provider

The project guidelines (*Procure Recycled: Paving the Way – Phase 2 Initiative (Rubber) – Demonstration Project Guidelines*) included a monitoring plan to assess pavement performance over time and evaluate the benefits of using CRM asphalt (wet method) in road construction.

The monitoring plan measured the functional and structural performance of the pavement over approximately 12 months at three key intervals: immediately after construction (0-1 months), after 6 months, and after 12 months. The field assessment included measurements of:

- Pavement macrotexture
- Rutting depth under the wheel path
- Roughness, assessed using the International Roughness Index (IRI)

Although a one-year monitoring period may not provide a comprehensive long-term prediction of pavement deterioration, the collected data points establish a trend, offering valuable insights. Additionally, the monitoring plan was designed to serve as a foundation for further assessments, potentially conducted by the individual councils.

Infrastructure Management Group (IMG) was selected by SSROC as the preferred pavement monitoring provider. SSROC commissioned IMG to carry out assessments at Year 0 (construction phase), after 6 months (second monitoring), and after 12 months (final monitoring). The last monitoring activity took place in June–July 2024, with the data made available to AfPA in September 2024.

2.5 Other project stakeholders

2.5.1 Project sponsor

Tyre Stewardship Australia (TSA) is an organisation committed to developing sustainable solutions for end-of-life tyres (EOLT) in Australia. Its primary focus is to create productive outcomes for used tyres by promoting the use of locally sourced tyre-derived products across various industries, including road construction.

TSA provided financial support for certain project activities and offered technical assistance by facilitating engagement with tyre recyclers in New South Wales. A comprehensive body of knowledge on the use of CR in asphalt roads is available on the TSA website.

2.5.2 SSROC

The Southern Sydney Regional Organisation of Councils (SSROC) is an incorporated association of 12 local councils, originally established in 1986. It serves as a collaborative platform for member councils to exchange ideas, address regional challenges, and contribute to the long-term sustainability of the region. SSROC also advocates on behalf of its member councils to ensure that key regional issues are addressed at all levels of government.

In November 2019, SSROC released a Memorandum of Understanding (MoU) to prioritise the use of recycled materials in procurement, provided that cost and quality requirements are met. The MoU also aimed to establish a common framework for regional procurement of products containing recycled content. It was signed by all 11 SSROC councils and five non-SSROC councils and was strategically released the day before the Coalition of Australian Governments (COAG) announced its export ban timeline for unprocessed recyclable materials.

This project was designed to identify and address barriers and opportunities to increase the use of CR in roads while fostering a local market for Australian recycled CR in alignment with the COAG export ban. Following the demonstration projects, SSROC aims to incorporate CR asphalt into the range of products available through the Sustainable Pavements contract.

2.5.3 Tyre recyclers and crumb rubber producers

CR for this project was supplied by Tyrecycle and D&N Rubber Refinery, two CR manufacturers based in the Sydney area, New South Wales.

Tyrecycle operates several dedicated tyre processing plants across Australia, equipped with advanced rubber manufacturing capabilities. Its Erskine Park (NSW) facility, opened in 2021, is a state-of-the-art manufacturing plant capable of processing tyres from various sources, including passenger, truck, and off-the-road (OTR) tyres.

D&N Rubber Refinery collaborates closely with a range of clients, including bitumen suppliers, throughout the manufacturing process - from design and development to the final production of rubber products. Its Smithfield (NSW) facility is equipped with state-of-the-art recycling machinery.

Both manufacturers are accredited by TSA.

3 Project Timeline

November – December 2021 – Request for Information (RFI)
SSROC collected information from suitably qualified contractors of the Sustainable Pavements – Road Construction Materials and Related Services contract through a Request for Information (RFI), in accordance with the Innovation and Benefits Realisation clause. The purpose of the RFI was to determine the current availability and supply chain activities of pavement materials that incorporate recycled rubber. A technical analysis of the information provided through this RFI was conducted to develop recommendations on appropriate high-potential mixes for councils to demonstrate in a multi-council demonstration project.
January – June 2022
RFI response analysis report; AfPA presented RFI findings and organised a workshop to determine the projects' needs.
August 2022
Guidelines were developed by AfPA for the set-up of the field demonstration projects. AfPA presented the guidelines after consultation with individual council engineers and staff members.
June 2023 - August 2023
Field demonstration projects were carried out during this period by the participating SSROC councils and asphalt contractors. The first pavement monitoring took place over this period.
December 2023 – January 2024
The second pavement monitoring was conducted.
June - July 2024
The third pavement monitoring was conducted.
September - December 2024
Field monitoring data collection and analysis. Final report writing.

4 Field Demonstration Projects

4.1 Bayside Council, Willison Rd

4.1.1 Project Site description

Paving operations at Bayside City Council were conducted on Willison Rd. in May 2023 by Boral Asphalt NSW. Willison Rd. is located in the suburb of Bexley in Sydney, New South Wales (Figure 1). The road runs through a residential area. The project included the resurfacing of the section of Willison Rd. between Forest Rd. and Byrnes St. This section presented extensive longitudinal cracking along the wheel paths and joints, and previous patching interventions, mostly in the direction of traffic from Willison Rd. towards Railway St. Potholes were also scattered along Willison Rd. both in the traffic and parking lanes.

A deeper than usual asphalt mill and fill intervention (60 mm) was planned by the Council to address the pavement distresses. Two different asphalt mix designs were laid, both of them included CRM asphalt. However, the source of the CR was different with the first section using CR from truck tyres (TT) exclusively, whereas the second section only used CR from passenger car tyres (PT). Both sections were resurfaced using a gap graded CRM asphalt mix (wet method) with approximately 18% of rubber by weight of the binder.

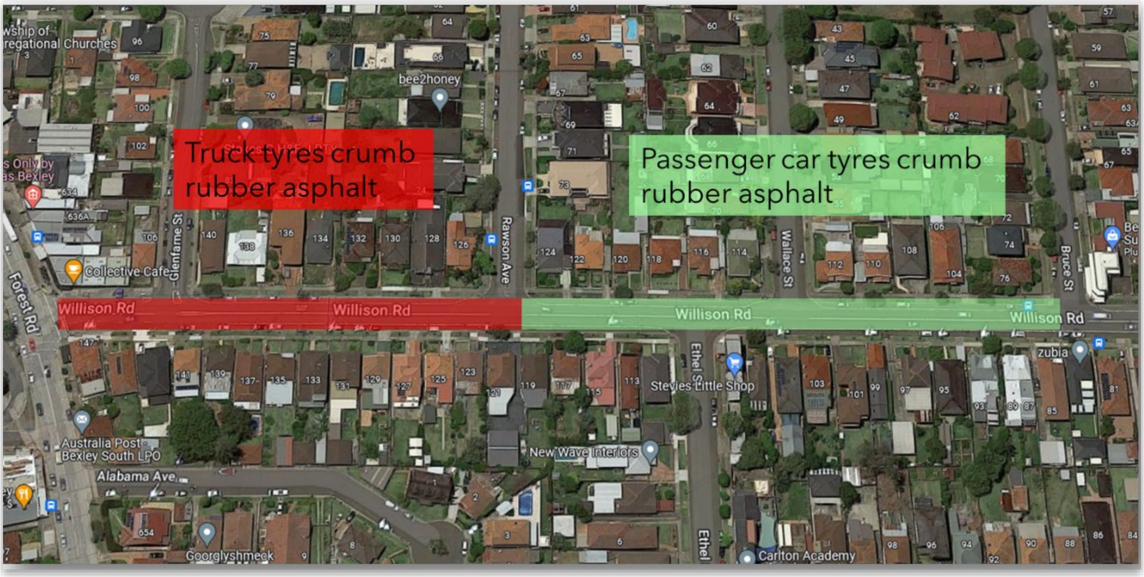


Figure 1 Project site at Bayside City Council The green hatched area shows the location of the passenger car tyres CRM asphalt mix, whereas the red hatched area shows the truck tyres CRM asphalt mix.

4.1.2 Materials and Mix design

The TT CRM asphalt mix was identified by the contractor with the acronym GGA14 A18R Sasobit TT, meaning that a gap graded asphalt mix (GGA), 14 mm nominal maximum aggregate size, A18R binder (according to Austroads ATS3110 classification, approximately 18% of CR by weight of the binder) was used for the project. The mix also included CR from TT only and a warm mix asphalt additive (Sasobit). The PT CRM asphalt mix was identified with the acronym GGA14 A18R Sasobit PT, with the only difference of using PT to produce the CR incorporated in the asphalt mix.

The addition of a warm mix asphalt additive was recommended by the project guidelines to reduce the production and compaction temperatures. All the materials used in this project were defined based on the indications provided by AfPA although the final choice of mix design and material was made jointly by the council and the contractor.

The fine and coarse aggregate proportions were similar for both mixes, so was the bitumen/binder content; 7.1% binder by total weight of the mix for the TT CRM asphalt and 7.3% binder content for the PT CRM asphalt. Small differences between plant-produced batches should be expected.

It was estimated by the contractor that approximately 168 TT and 840 PT were recycled and used in this project as CR (#30 mesh).

4.1.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over two days. Specifically, the TT CRM asphalt mix was paved on the 30th of May 2023, whereas the PT CRM asphalt mix was laid on the 31st of May 2023.

The distance from Boral's asphalt plant to the construction site was approximately 11.8 km. After traffic management was in place, the profiler milled the road surface and a SAMIprime K2 or CRS60 tack coat were applied after sweeping where applicable. The rate of application was 1.0 L/m^2 and 0.3 L/m^2 for the K2 prime and CRS60 tack coat, respectively. Asphalt paving operations continued as per usual procedure using a Roadtek RP175EX paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums).

According to the paving records supplied by the contractor, approximately 300 tonnes of TT CRM asphalt and 318 tonnes of PT CRM asphalt were produced. Overall, approximately 2117 m^2 of Willison Rd. were paved using TT CRM asphalt, whereas approximately 2348 m^2 were paved using PT CRM asphalt.

The contractor did not report of any issues occurring during the paving operations in Bextley, nor of any complaints due to asphalt fumes.

4.1.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 27th July 2023, approximately two months after construction. The same measurements were conducted on the 10th of January 2024, approximately 7 months after initial construction, and on the 10th of July 2024, approximately 13 months after initial construction.

The outcome of the three monitoring runs is shown in Figure 2 to Figure 4. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period; however, the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic values (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).

Figure 2 to Figure 4 are related to the traffic direction that goes from Byrnes St. to Forest Rd.

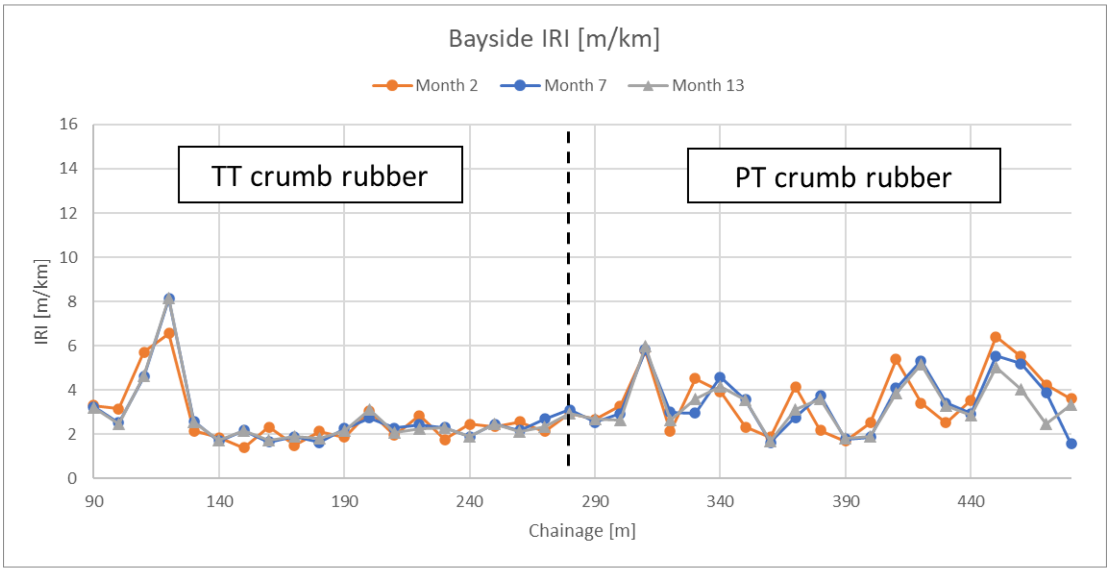


Figure 2 Evolution of the International Roughness Index (IRI, m/km) at Bayside City Council over 13 months

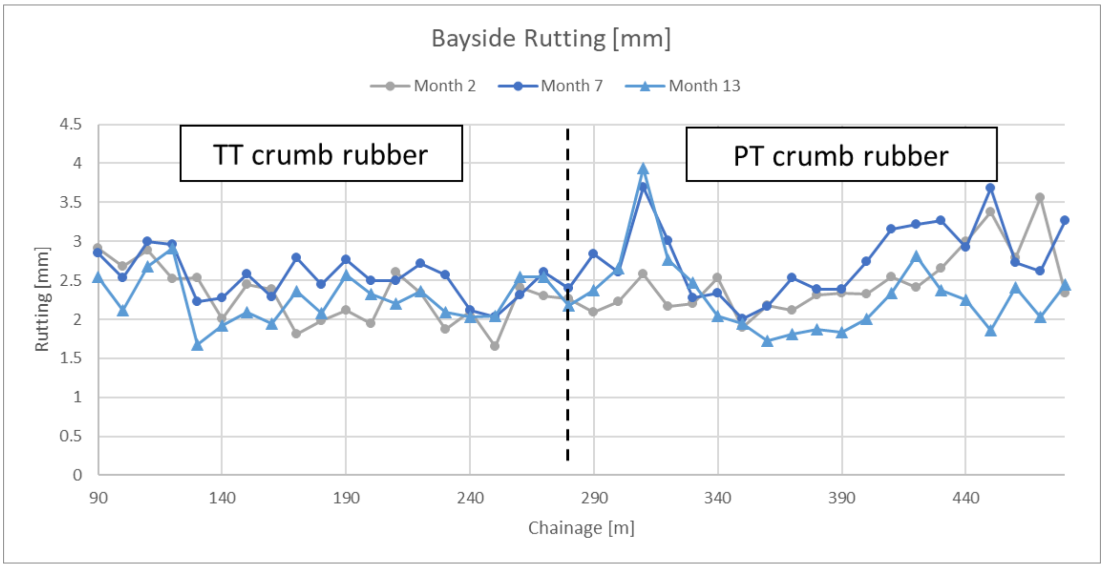


Figure 3 Evolution of rutting depth (mm) at Bayside City Council over 13 months

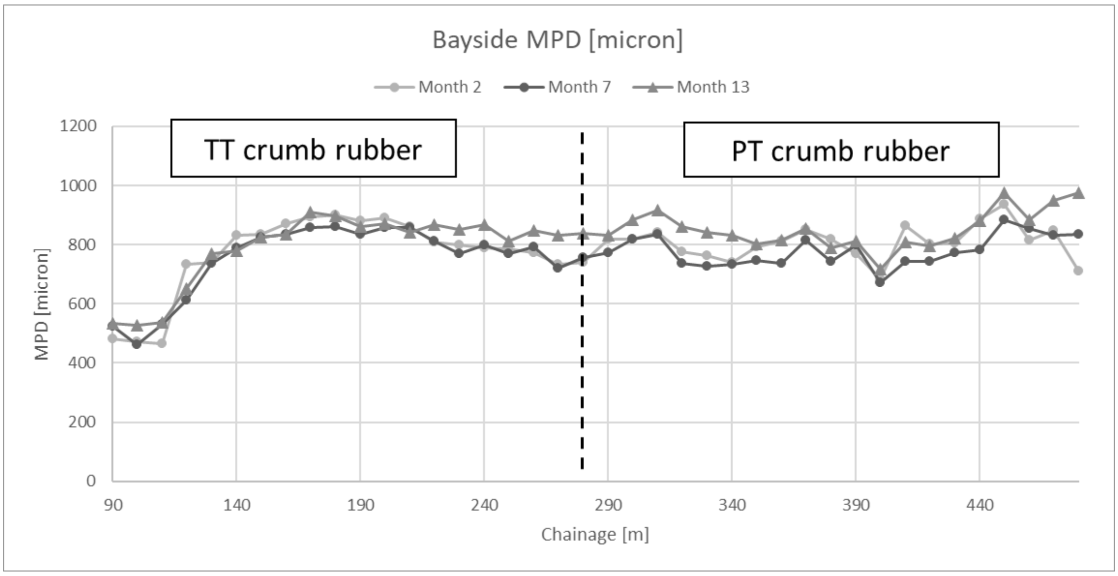


Figure 4 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at Bayside City Council over 13 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 13-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed on the evolution of IRI over time; the three sets of measurements at 2-7-13 months are largely consistent. A localised irregularity (IRI > 8 m/km) can be found at the beginning of the TT CR section. In general, average values of IRI between 2.5 m/km and 3.5 m/km are consistent with those found for a residential road after 1 year of operation. Other external factors might have affected the IRI measurement in an urban environment, such as continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc. Construction operations might have also contributed to slight differences in IRI. On average, the TT CRM asphalt section provides a smoother ride to users although the variability of the IRI values throughout the road makes the two sections similar.
- The average rutting depth after 13 months was similar in both sections. The source of CR did not seem to have any effect on the average rutting depth, hence suggesting that PT CRM is as good as the more common TT CRM asphalt.
- As expected, no major difference was found in the macrotexture of the two road sections. In fact, macrotexture is mostly influenced by the aggregate gradation rather than by the type of binder.

Refer to Table 3 and Figure 5 for a detailed analysis of the trends observed.

Table 3 Average values of IRI, rutting depth, and macrotexture at Bayside City Council

	TT Crumb rubber	St.dev.	PT Crumb rubber	St.dev.
Average IRI [m/km]	2.7	1.4	3.4	1.1
Average Rutting depth [mm]	2.3	0.3	2.3	0.5
Average MPD [micron]	788.0	122.6	852.3	65.2

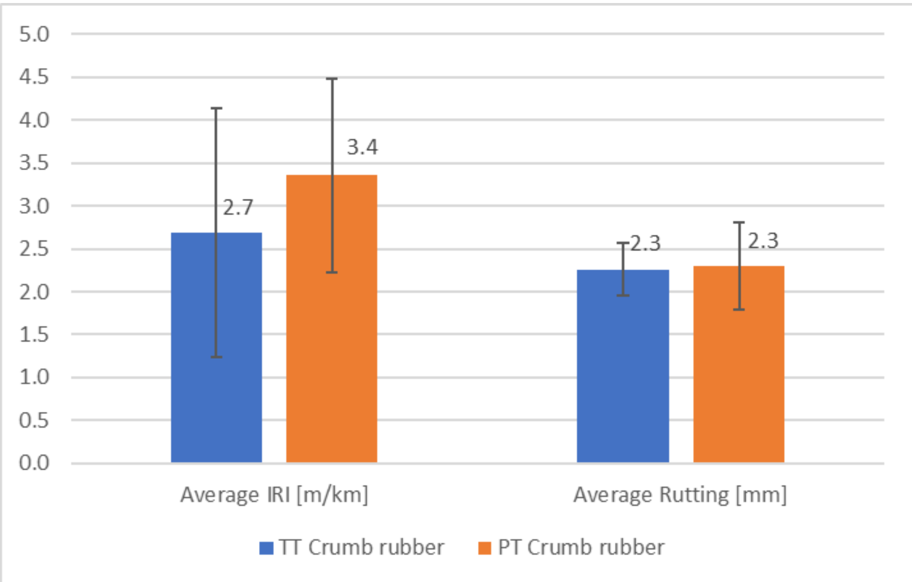


Figure 5 Average values of IRI, rutting depth, and macrotexture at Bayside City Council

4.2 Burwood Council, Park Ave

4.2.1 Project Site description

Paving operations at Burwood City Council were conducted on Park Av. in June 2023 by Boral Asphalt NSW. Park Ave. is located in the inner western part of Sydney, New South Wales (Figure 6). The road is in a residential area, but it is considered a high profile street due to its location next to Burwood Park and the town centre close to a large shopping mall. Park Ave stretches from Burwood Rd to Park Rd in Burwood. The road pavement showed signs of fatigue damage with extensive crocodile cracking, especially on the approaches at the two ends of Park Ave with Burwood Rd and Park Rd. Localised distresses and differential settlements due to utility services were also evident at the approach with Burwood Rd.

The Council planned a maintenance intervention that included some deep lift areas (150 mm asphalt base layers) and an overall asphalt mill and fill (50 mm) to address the pavement distresses. Four different asphalt mixes were used in this project, two for the asphalt base layers (one conventional and one CRM) and two for the wearing course (one conventional and one CRM). The conventional asphalt mixes were dense graded, whereas the CRM mixes (wet method) were gap graded with approximately 18% of CR by weight of the binder.

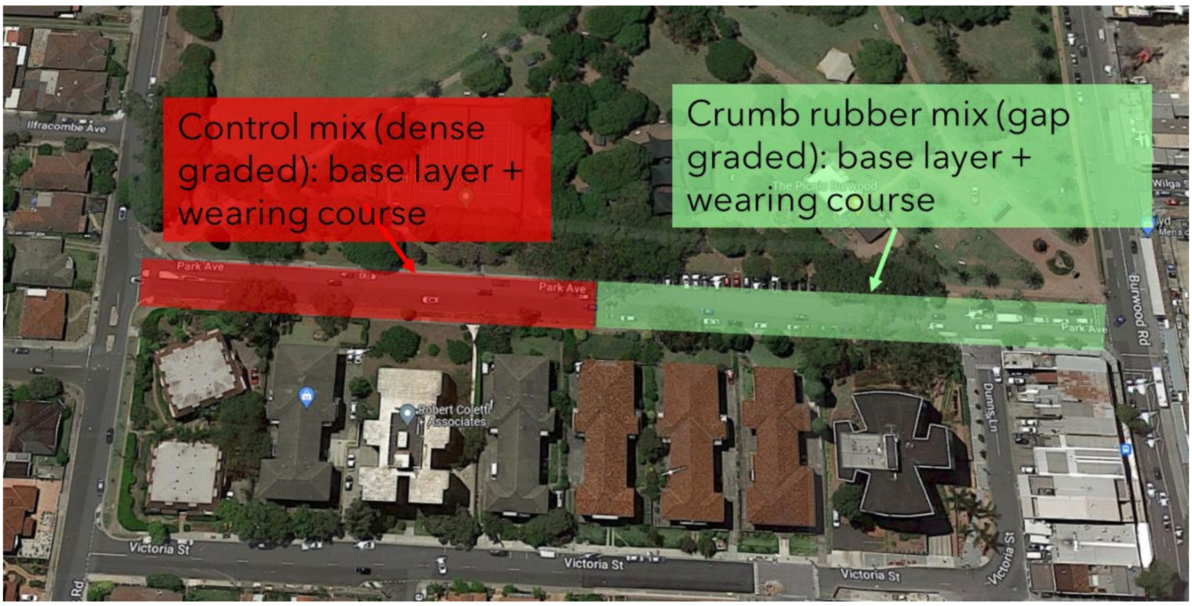


Figure 6 project site at Burwood City Council

The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.2.2 Materials and Mix design

The conventional asphalt mixes were identified by the contractor with the acronyms DG14 C450 2.5%GS (wearing course) and DG20 C450 15%R 10%GS (base layer). The first mix is a dense graded asphalt mix (DG), 14 mm nominal maximum aggregate size, C450 bitumen, and 2.5% recycled crushed glass (2.5%GS) as partial sand replacement. The second mix, used for the asphalt base layer is a dense graded asphalt mix (DG), 20 mm nominal maximum aggregate size, C450 bitumen, 15% RAP, and 10% recycled crushed glass (10%GS) as partial sand replacement.

The CRM asphalt mixes were identified by the acronyms GGA14 A18R Sasobit TT (wearing course) and GGA20 A18R Sasobit (base layer). The first is a gap graded (GGA), 14 mm nominal maximum aggregate size, A18R binder (according to Austroads ATS3110 classification, approximately 18% of CR by weight of the binder), and a warm mix asphalt additive (Sasobit). The source of CR was identified as TT. The second mix is a gap graded (GGA), 20 mm nominal maximum aggregate size, A18R binder (according to Austroads ATS3110 classification, approximately 18% of CR by weight of the binder), and a warm mix asphalt additive (Sasobit). The source of CR was identified as a combination of TT and PT.

The addition of a warm mix asphalt additive was recommended by the project guidelines to reduce the production and compaction temperatures. All the materials used in this project were defined based on the initial indications provided by AfPA although the final choice of mix design and material was made jointly by the council and the contractor.

The fine and coarse aggregate proportions were highly dissimilar in this particular project. In fact, the addition of high content of CR in the binder (i.e. 18%) requires either a gap-graded or an open-graded particle size distribution. The bitumen/binder contents were 5.1% and 4.6% by total weight of the mix for the wearing course and base layer of the conventional asphalt, respectively, and 7.1% and 6.8% binder content for the wearing course and base layer of the CRM asphalt, respectively. The higher binder content and presence of 18% CR in the asphalt mix results in a more expensive mix although greater performance and durability should be expected over time.

It was estimated by the contractor that approximately 151 truck tyres and 208 passenger car tyres were recycled and used in this project as CR (#30 mesh).

4.2.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over four days due to the size of the project and variety of mix designs. Once the asphalt base layer was laid, traffic was reopened for approximately two weeks before the wearing course was laid. Specifically, the construction works were conducted on the 1st and 6th of June 2023 for the base layers, and 19th and 20th of June 2023 for the wearing courses.

The distance from Boral's asphalt plant to the construction site was approximately 6.2 km. After traffic management was in place, the profiler milled the road surface and a SAMIprime K2 or CRS60 tack coat were applied after sweeping where applicable. The rate of application was 1.0 L/m^2 and 0.3 L/m^2 for the K2 prime and CRS60 tack coat, respectively. Asphalt paving operations continued as per usual procedure using a Roadtek RP175EXpaver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums). According to the paving records supplied by the contractor, approximately 270 tonnes (base layer) and 251 tonnes (wearing course) of conventional asphalt, and 170 tonnes (base layer) and 190 tonnes (wearing course) of CRM asphalt were produced. Overall, approximately 2092 m^2 of Park Ave. were paved using conventional asphalt, whereas approximately 1414 m^2 were paved using CRM asphalt.

The contractor did not report of any issues occurring during the paving operations in Burwood, nor of any complaints due to asphalt fumes.

4.2.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 27th of July 2023, approximately one month after construction. The same measurements were conducted on the 13th of January 2024, approximately 6 months after initial construction, and on the 11th of July 2024, approximately 12 months after initial construction.

The outcome of the three monitoring runs are shown in Figure 7 to Figure 9. The authors did not receive information about the traffic volumes and its characteristics during the 12-month monitoring period although the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic values (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).

Figure 7 to Figure 9 are related to the traffic direction that goes from Park Rd. to Burwood Rd.

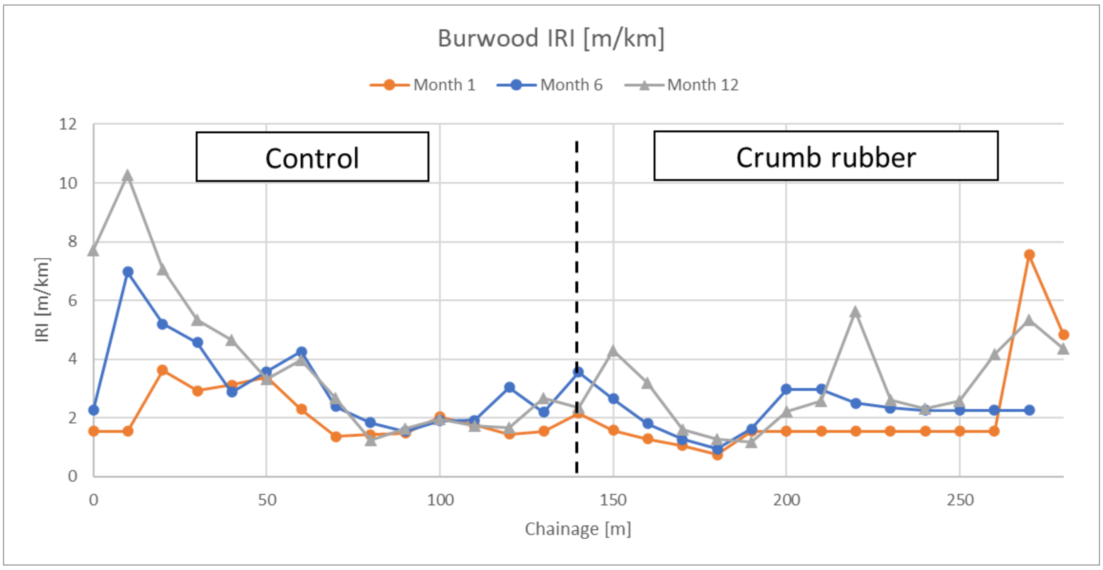


Figure 7 Evolution of the International Roughness Index (IRI, m/km) at Burwood City Council over 12 months

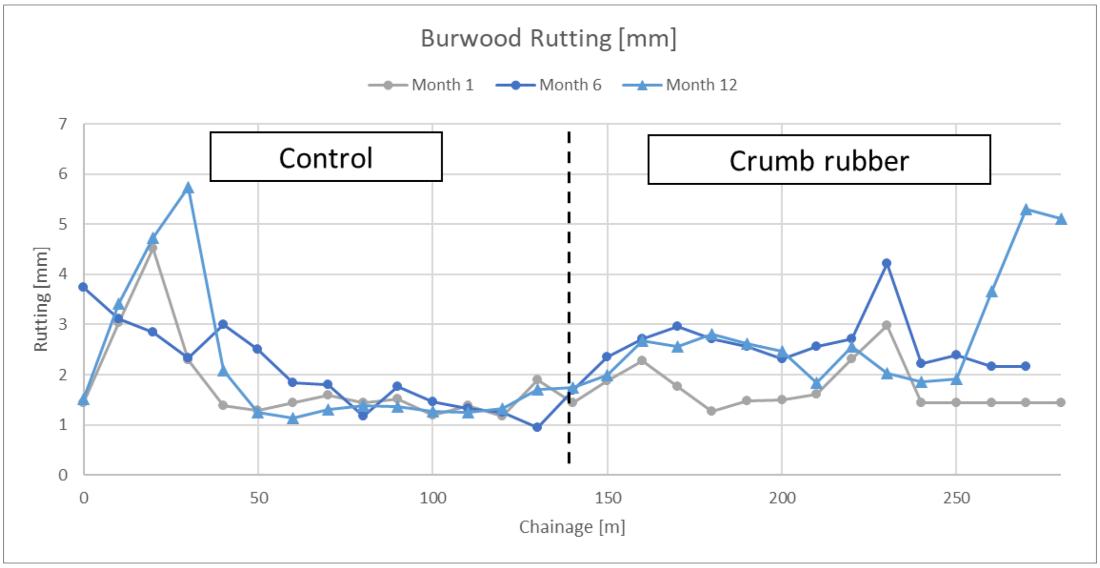


Figure 8 Evolution of rutting depth (mm) at Burwood City Council over 12 months

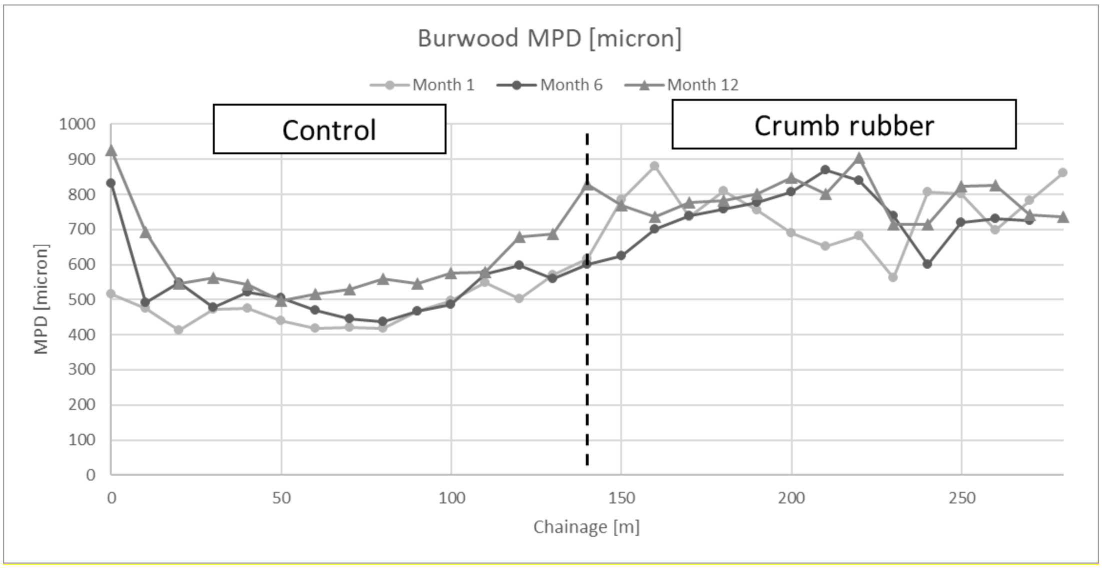


Figure 9 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at Burwood City Council over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- The evolution of IRI over time suggests that IRI values have increased over the 12-month period. In general, average values of IRI between 3 m/km and 4 m/km are in the mid-high range for a road that has been resurfaced within 12 months. On average, the CRM asphalt section provides a smoother ride to users although the variability of the IRI values throughout the road makes the two sections similar. Other external factors might have affected the IRI measurement in an urban environment, such as continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc. Construction operations might have also contributed to slight differences in IRI. In this project, the road was re-opened to traffic for two weeks after laying the base layer and prior to the paving of the wearing course.
- The average rutting depth after 12 months was similar in both sections although the average rutting depth of the CRM section was 33% higher than the conventional asphalt section. Note that the conventional asphalt included 15% RAP (base layer), which could have contributed to stiffening the mix thus reducing the rutting depth over time. The Council is encouraged to continue monitoring the rutting depth over time for a more comprehensive evaluation of the situation.
- Interestingly, the macrotexture of the road section where CRM asphalt was used is higher, on average, than in the control section. Although this outcome might suggest that the use of CR (wet method) can positively affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.), other road sections within the SSROC project do not seem to confirm nor deny this finding. Most probably, the difference in macrotexture is dictated by the largely dissimilar aggregate distribution (i.e. dense graded vs gap graded).

Refer to Table 4 and Figure 10 average values of IRI, rutting depth, and macrotexture at Burwood City Council for a detailed analysis of the trends observed.

Table 4 Average values of IRI, rutting depth, and macrotexture at Burwood City Council

	Control	St.dev.	Crumb rubber	St.dev.
Average IRI [m/km]	3.9	2.67	3.1	1.44
Average Rutting depth [mm]	2.1	1.41	2.8	1.12
Average MPD [micron]	617.8	123.06	784.0	54.74

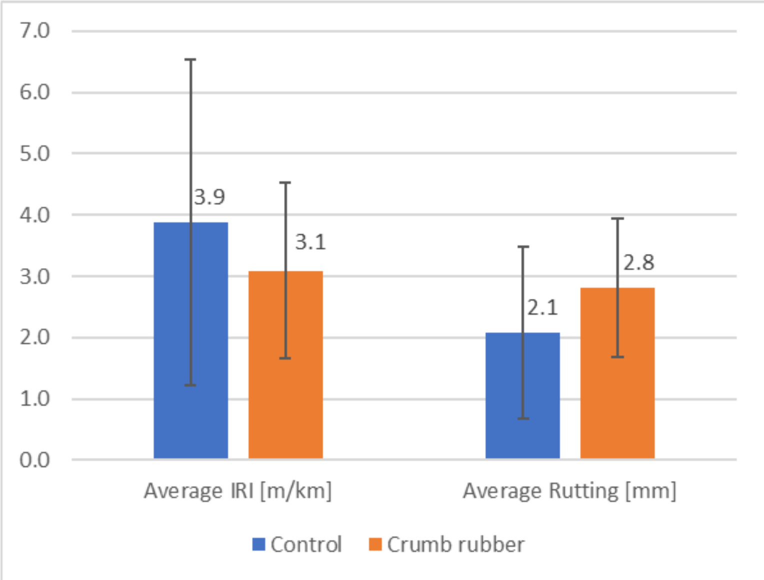


Figure 10 Average values of IRI, rutting depth, and macrotexture at Burwood City Council

4.3 Woollahra Municipal Council, Edgecliff Rd

4.3.1 Project Site description

Paving operations at the City of Woollahra were conducted on Edgecliff Rd. in June 2023 by Boral Asphalt NSW. Edgecliff Rd is located in the inner eastern suburbs of Sydney in New South Wales (Figure 11). It runs North-South from New South Head Rd to Old South Head Rd in Woollahra. The section of Edgecliff Rd due for resurfacing extended from Adelaide St to Kendall St.

Edgecliff Rd. presented a rigid pavement made of concrete slabs laid a few decades ago. The slabs showed sign of deterioration, cracking, and joint defects. Therefore, an asphalt overlay (40 mm) was planned by the Council in an attempt to provide road users with a smoother and safer surface while avoiding reflective cracking. Three different asphalt mix designs were laid: a conventional dense graded asphalt mix, a dense graded CRM asphalt mix (wet method) with approximately 15% of CR by weight of the binder, and a CRM asphalt mix (wet method, 15% CR by weight of the binder) with the addition of a geogrid in between the concrete slabs and the asphalt surface layer. The asphalt mixes identified in green and light blue in the Figure 11 were essentially the same mix (aggregate type, binder type and content, etc.) with the only difference being the presence of the geogrid.

Figure 11Project site at the City of Woollahra

The green and light blue hatched areas show the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.3.2 Materials and Mix design

The conventional asphalt mix was identified by the contractor as DG10 C320 15%R 2.5%GS, meaning that a dense graded asphalt mix (DG), 10 mm nominal maximum aggregate size, C320 bitumen, was used for the project. 2.5% recycled crushed glass (2.5%GS) was also incorporated into the asphalt mix as partial sand replacement, together with 15% RAP.

The CRM asphalt mix was identified by the acronym DG10 S45R 2.5%GS Sasobit, meaning that a dense graded mix (DG), 10 mm nominal maximum aggregate size, S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder) was used for the project. The mix also included 2.5% recycled crushed glass (2.5%GS) and a warm mix asphalt additive (Sasobit). The addition of a warm mix asphalt additive was recommended by the AfPA project guidelines to reduce the production and compaction temperatures. All the materials used in this project were defined based on the initial indications provided by

AfPA although the final choice of mix design and source of material was made jointly by the council and the contractor.
The fine and coarse aggregate proportions were similar for both mixes, so was the bitumen/binder content; 5.7% bitumen by total weight of the mix for the conventional asphalt and 5.9% binder content for the CRM asphalt. A minimum tolerance should always be accounted for at the production plant.
It was estimated by the contractor that approximately 66 TT and 265 PT were recycled and used in this project in the form of CR (#30 mesh).

4.3.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over three days to minimise traffic disruptions in the area. Specifically, the conventional asphalt mix was paved on the 14th of June 2023, whereas the CRM mix was laid on the 16th and 18th of June 2023.
The distance from Boral's asphalt plant to the construction site was approximately 23 km. After traffic management was in place, the profiler milled the road surface and various treatments were applied depending on the condition of the road. Specifically, crack sealing and tack coat were applied after milling on the conventional asphalt section and on the first of the two CRM asphalt sections, whereas crack sealing, a tack coat, and a geogrid (i.e. high-modulus fibres in combination with a nonwoven fabric) were applied on the last CRM asphalt sections towards the intersection with Kendall St. CRS60 tack coat was applied at a rate of application of 0.3 L/m^2. Asphalt paving operations continued as per usual procedure using a Roadtek RP175EX paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums).
According to the paving records supplied by the contractor, approximately 117 tonnes of asphalt (conventional asphalt) were produced and laid on the 14th of June 2023 and 315 tonnes (CRM asphalt) on the 16th-18th of June 2023. Overall, approximately 1054 m^2 of Edgecliff St. were paved using conventional asphalt, whereas approximately 3084 m^2 were paved using CRM asphalt.
The contractor did not report of any issues occurring during the paving operations at Edgecliff St., nor of any complaints due to asphalt fumes.

4.3.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 27th July 2023, approximately one month after construction. The same measurements were conducted by IMG on the 11th of January 2024, approximately 6 months after initial construction, and on the 11th of July 2024, approximately 12 months after initial construction.

The outcome of the three monitoring runs are shown in Figure 12 to Figure 14. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. This particular road had the highest traffic amongst all the SSROC projects, i.e. 25,000 vpd.

Figure 12 to Figure 14 are related to the traffic direction that goes from Adelaide St. towards Old South Head Rd.

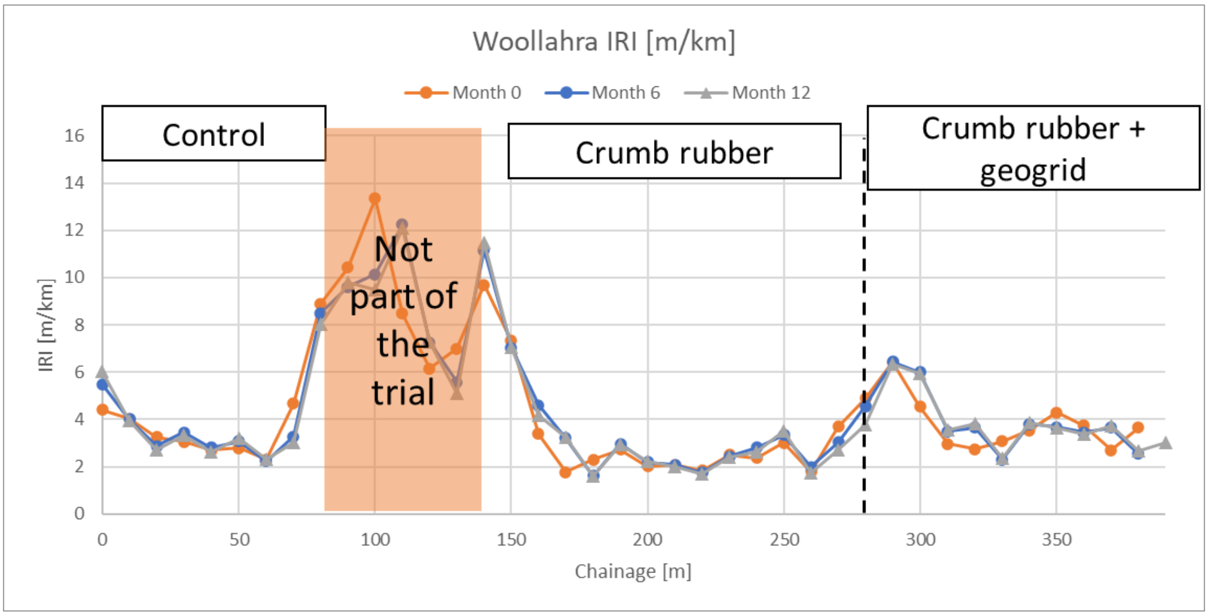


Figure 12 Evolution of the International Roughness Index (IRI, m/km) at City of Woollahra over 12 months

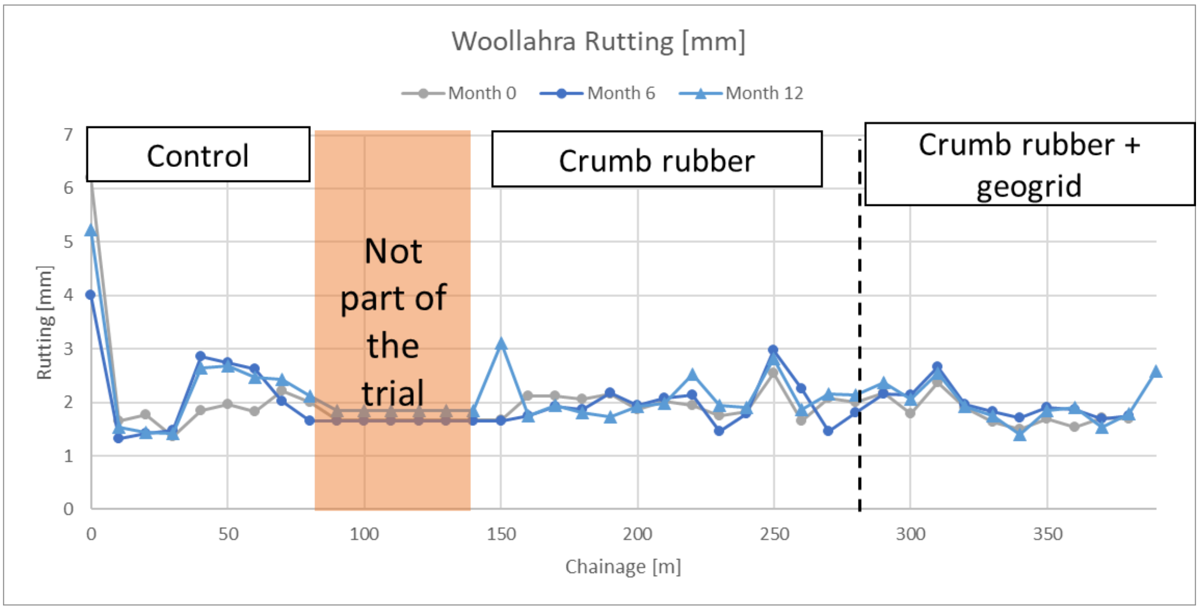


Figure 13Evolution of rutting depth (mm) at City of Woollahra over 12 months

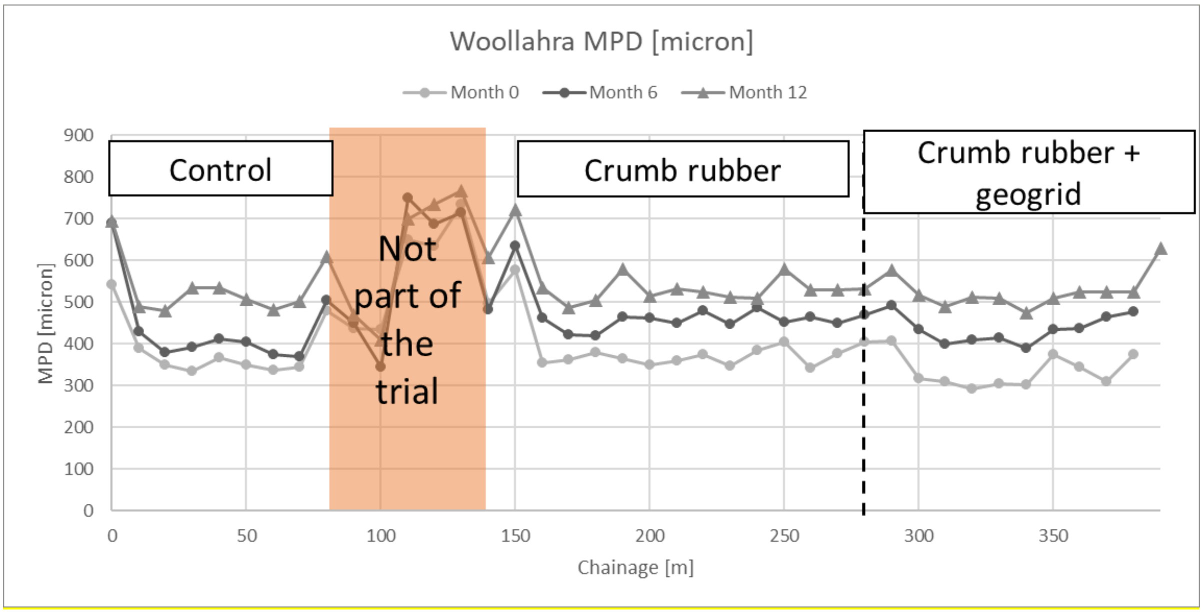


Figure 14 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at City of Woollahra over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses can evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions. For this particular project, the reflective cracking from the underlaying concrete slabs should be monitored visually at least twice a year by the council engineers to evaluate the effectiveness of CRM asphalt with/without a geogrid to slow down the appearance of cracking on the surface compared to conventional asphalt.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed on the evolution of IRI over time; the three sets of measurements at 1-6-12 months are largely consistent. In general, average values of IRI between 3 m/km and 4 m/km are in the mid-high range for a road that has been resurfaced within 12 months. Other external factors might have affected the IRI measurement in an urban environment, such as continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc. Construction operations might have also contributed to slight differences in IRI.
- The CRM asphalt sections show average rutting depth after 12 months below the value recorded for the control section. In general, approximately 12 to 21% reduction in average rutting depth was observed over the first 12 months at locations where CR is used in the asphalt mix.
- No major changes were observed in the macrotexture of the road. The use of CR(wet method) does not seem to affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.).

Refer to Table 5 and Figure 15 for a detailed analysis of the trends observed.

Table 5 Average values of IRI, rutting depth, and macrotexture at City of Woollahra

	Control	St.dev.	Crumb rubber	St.dev.	Crumb rubber + geogrid	St.dev.
Average IRI [m/km]	3.9	1.9	3.0	1.4	3.9	1.2
Average Rutting depth [mm]	2.4	1.2	2.1	0.4	1.9	0.3
Average MPD [micron]	536.8	71.1	542.2	57.9	517.8	26.2

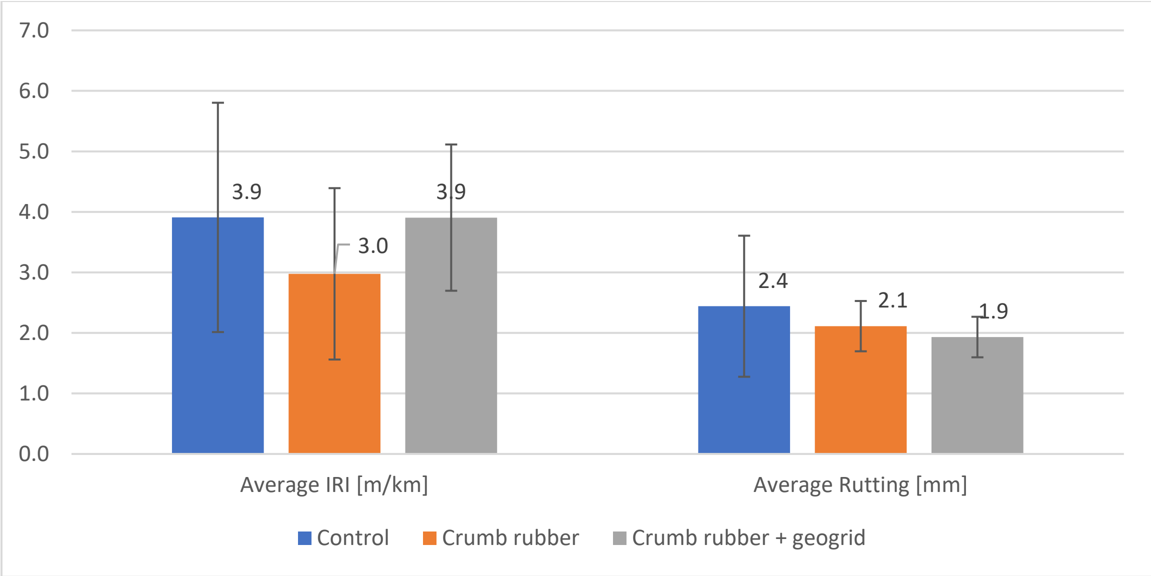


Figure 15 Average values of IRI, rutting depth, and macrotexture at City of Woollahra

4.4 Randwick City Council, The Causeway.

4.4.1 Project Site description

Paving operations at Randwick City Council were conducted on The Causeway in June 2023 by Boral Asphalt NSW. The Causeway is located in the southern east suburb of Maroubra in Sydney, New South Wales (Figure 16). The Causeway is a local road that runs Southwest-Northeast from Maroubra Rd to Torrington Rd in Maroubra. The project included the resurfacing of the section of The Causeway that extends from Maroubra Rd to First Ave. This section presented some fine transversal cracking and ravelling. Longitudinal cracking was also present towards the intersection with First Ave.

An asphalt mill and fill intervention (40 mm) was planned by the Council to address those pavement distresses. Two different asphalt mix designs were laid: a conventional dense graded asphalt mix and a dense graded CRM asphalt mix (wet method) with approximately 15% of CR by weight of the binder.

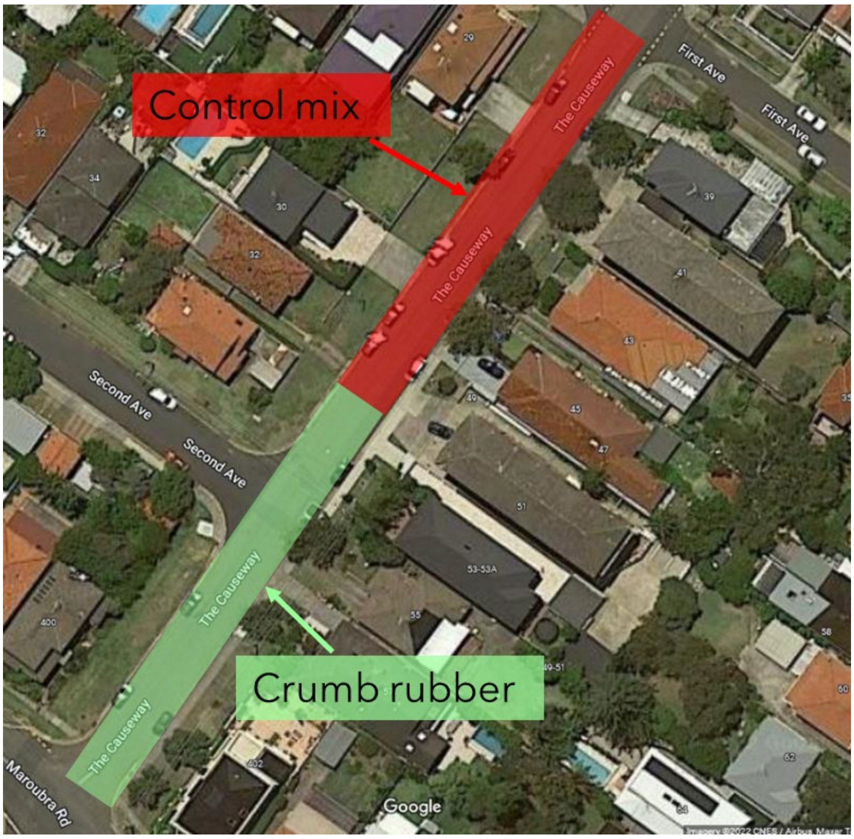


Figure 16 Project site at Randwick City Council. The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.4.2 Materials and Mix design

The conventional asphalt mix was identified by the contractor with the acronym DG10 C320 2.5%GS, meaning that a dense graded asphalt mix (DG), 10 mm nominal maximum aggregate size, C320 bitumen, was used for the project. Additionally, 2.5% recycled crushed glass (2.5%GS) was incorporated into the asphalt mix as partial sand replacement.

The CRM asphalt mix was identified by the acronym DG10 S45R Sasobit 2.5%GS, meaning that a dense graded mix (DG), 10 mm nominal maximum aggregate size, S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder) was used for the project. Additionally, the mix included 2.5% recycled crushed glass (2.5%GS) and a warm mix asphalt additive (Sasobit). The addition of a

warm mix asphalt additive was recommended by the AfPA project guidelines to reduce the production and compaction temperatures. All the materials used in this project were defined based on the indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and material.
The fine and coarse aggregate proportions were similar for both mixes, so was the bitumen/binder content; 6% bitumen by total weight of the mix for the conventional asphalt and 5.9% binder content for the CRM asphalt. Small differences between plant-produced batches should be expected.
It was estimated by the contractor that approximately 12 TT and 48 PT were recycled and used in this project as CR (#30 mesh).

4.4.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over two days due to the small size and logistics of the construction site. Specifically, the conventional asphalt mix was paved on the 19th of June 2023, whereas the CRM mix was laid on the 20th of June 2023.
The distance from Boral's asphalt plant to the construction site was approximately 24.5 km After traffic management was in place, the profiler milled the road surface and a SAMIprime K2 or CRS60 tack coat were applied after sweeping where applicable. The rate of application was 1.0 L/m^2 and 0.3 L/m^2 for the K2 prime and CRS60 tack coat, respectively. Asphalt paving operations continued as per usual procedure using a Roadtek RP175EX paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums). According to the paving records supplied by the contractor, approximately 75 tonnes of conventional asphalt and 75 tonnes of CRM asphalt were produced. Overall, approximately 729 m^2 of The Causeway were paved using conventional asphalt, whereas approximately 685 m^2 were paved using CRM asphalt.
The contractor did not report of any issues occurring during the paving operations in Maroubra, nor of any complaints due to asphalt fumes.

4.4.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 27th July 2023, approximately one month after construction. The same measurements were conducted on the 10th of January 2024, approximately 6 months after initial construction, and on the 11th of July 2024, approximately 12 months after initial construction.

The outcome of the three monitoring runs are shown in Figure 17 to Figure 19. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).

Figure 17 to Figure 19 are related to the traffic direction that goes from Maroubra Rd towards First Av.

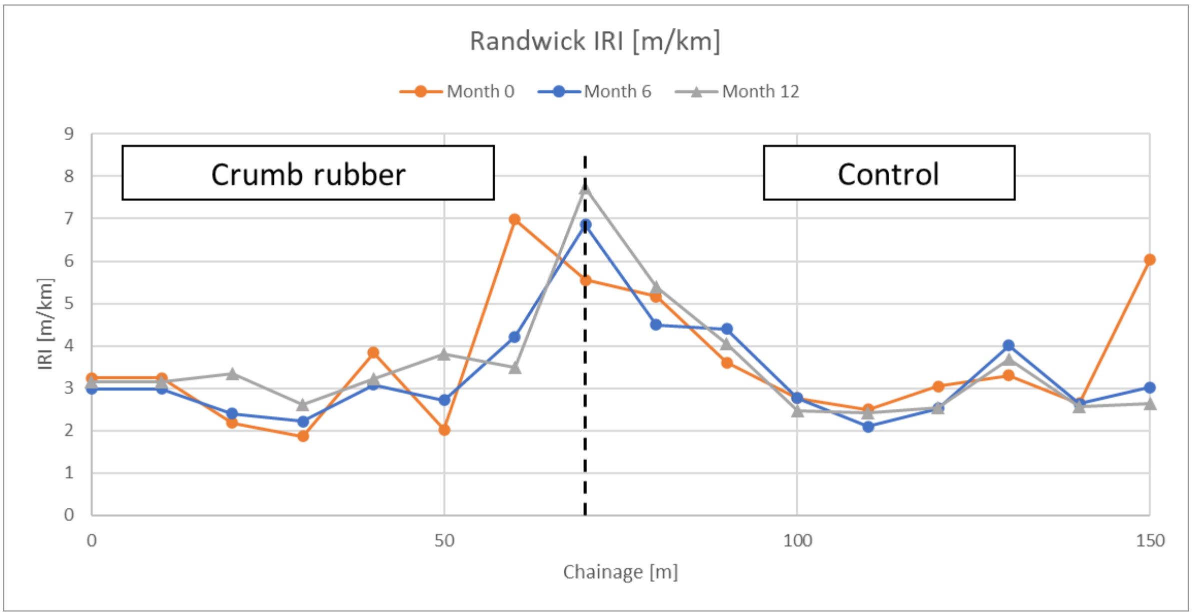


Figure 17 Evolution of the International Roughness Index (IRI, m/km) at Randwick City Council over 12 months

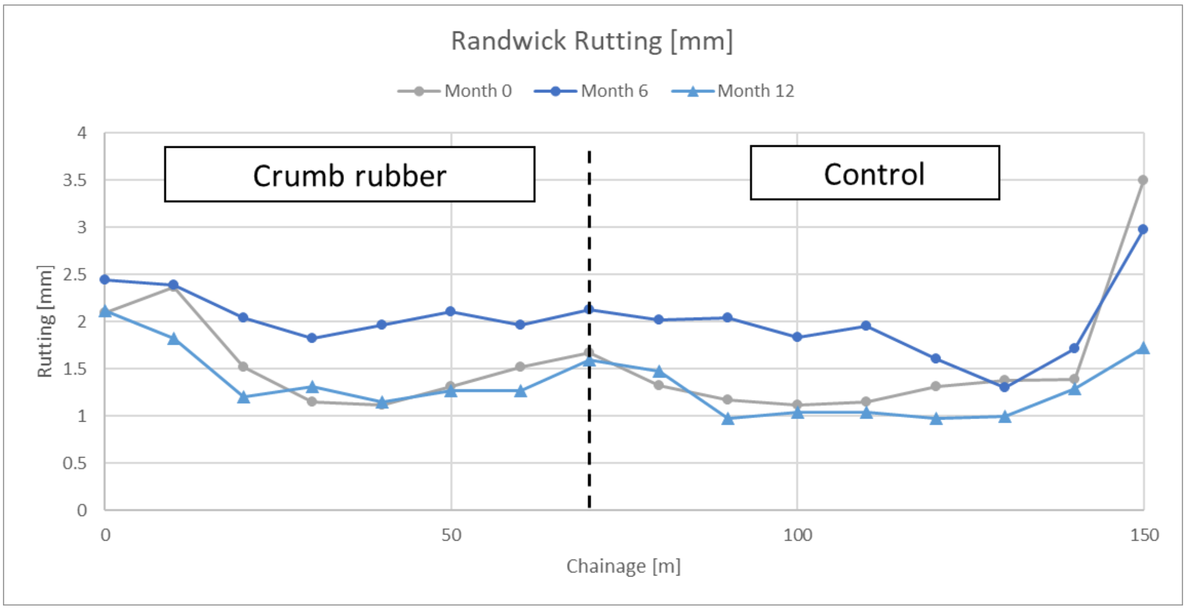


Figure 18 Evolution of rutting depth (mm) at Randwick City Council over 12 months

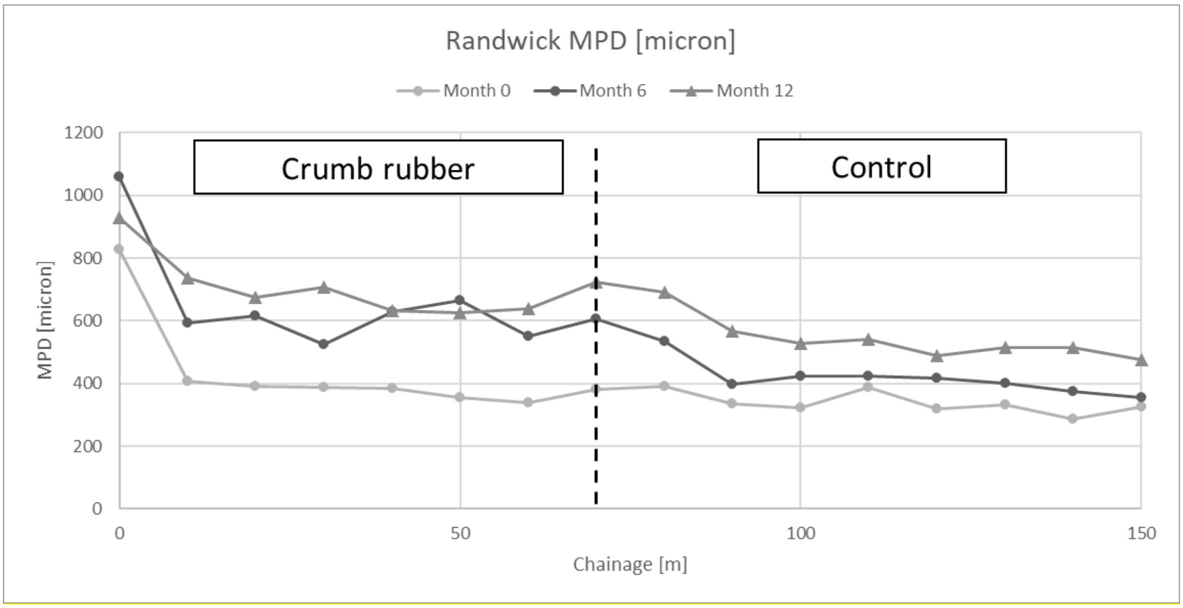


Figure 19 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at Randwick City Council over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed on the evolution of IRI over time; the three sets of measurements at 1-6-12 months are largely consistent. A localised irregularity (IRI > 7 m/km) can be found at the location where the two test sections join. In general, average values of IRI between 3 m/km and 4 m/km are in the mid-high range for a road that has been resurfaced within 12 months. Other external factors might have affected the IRI measurement in an urban environment, such as continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc. Construction operations might have also contributed to slight differences in IRI. On average, the control asphalt section provides a smoother ride to users although the variability of the IRI values throughout the road makes the two sections similar.
- The average rutting depth after 12 months was similar in both sections. No reduction in average rutting depth was observed at locations where CR is used in the asphalt mix. It should be noted that the rutting depth is minimal at both sites possibly indicating very low traffic levels.
- Interestingly, the macrotexture of the road section where CRM asphalt was used is generally higher than in the control section. Although this outcome might suggest that the use of CR (wet method) can positively affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.), other road sections within the SSROC project do not seem to confirm nor deny this finding.

Refer to Table 6 and Figure 20 for a detailed analysis of the trends observed.

Table 6 Average values of IRI, rutting depth, and macrotexture at Randwick City Council

	Control	St.dev.	Crumb rubber	St.dev.
Average IRI [m/km]	3.2	1.81	3.8	1.62
Average Rutting depth [mm]	1.2	0.28	1.5	0.35
Average MPD [micron]	540.2	67.44	708.2	99.01

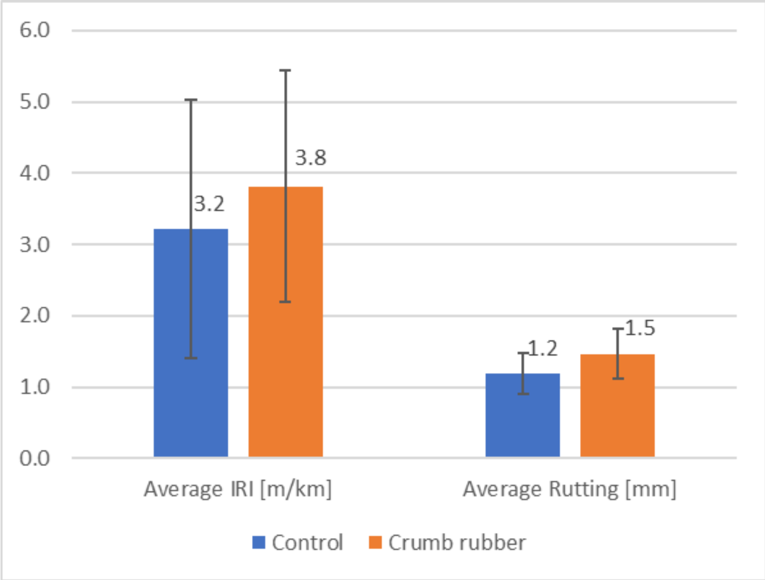


Figure 20 Average values of IRI, rutting depth, and macrotexture at Randwick City Council

4.5 Northern Beaches Council, The Circle.

4.5.1 Project Site description

Paving operations at Northern Beaches Council were conducted on The Circle in June 2023 by Boral Asphalt NSW. The Circle is located in the northeastern suburb of Narraweena in Sydney, New South Wales (Figure 21). The Circle is a local residential road that runs in a loop between Oceana St and Crete St in Narraweena. The project included various interventions aimed to convert the old sprayed sealed surface to an asphalt pavement due to increased traffic in the area. The Circle showed signs of significant longitudinal cracking and ravelling and has attracted some attention due to excessive noise. Crete St. presents crocodile cracking for more than 70% of its full length. Scattered patching has been conducted over the years on The Circle, which also showed significant cracking and ravelling.

The Council planned a maintenance intervention that included some deep lift areas (100 mm asphalt base layers) and an overall asphalt mill (20 mm) and fill (30 mm) surface layer to address the pavement distresses. Two different asphalt wearing course mixes were laid: a conventional dense graded asphalt mix and a dense graded CRM asphalt mix (wet method) with approximately 9% of rubber by weight of the binder. In the deep lift areas, a conventional dense graded asphalt mix was laid.

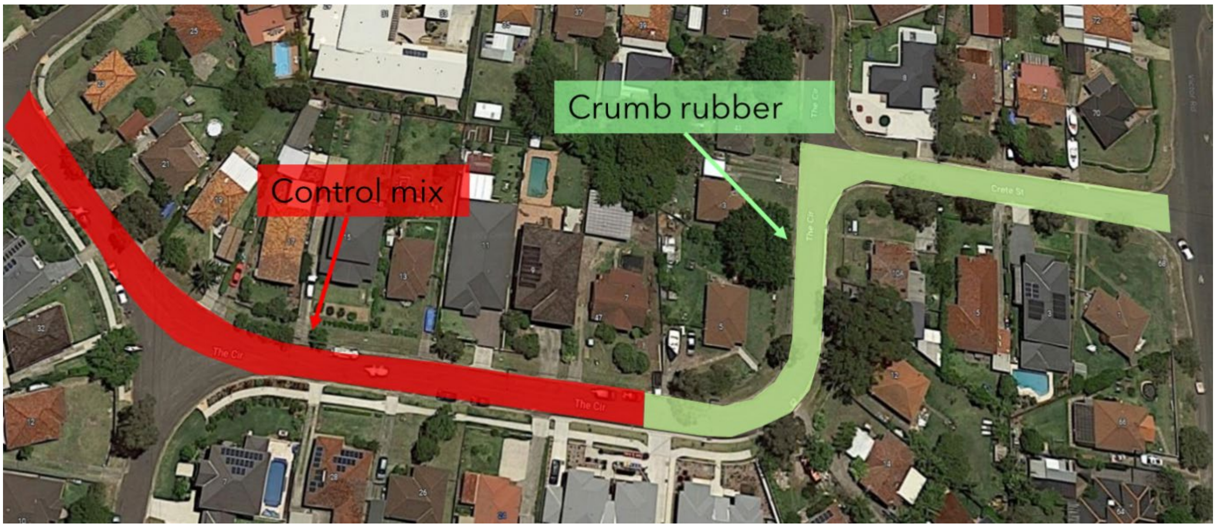


Figure 21 Project site at Northern Beaches Council. The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.5.2 Materials and Mix design

The conventional asphalt mixes were identified by the contractor with the acronym DG10 C320 0%GS (wearing course) and DG28 C320 30%RAP. The first mix is a dense graded asphalt mix (DG), 10 mm nominal maximum aggregate size, C320 bitumen, and no recycled crushed glass (0%GS) as partial sand replacement. The second mix, used for deep lift areas as an asphalt base layer, is a dense graded asphalt mix (DG), 28 mm nominal maximum aggregate size, C320 bitumen, and 30% RAP.

The CRM asphalt mix was identified by the acronym DG10 S9R 20%RAP 2.5%GS Sasobit, meaning that a dense graded mix (DG), 10 mm nominal maximum aggregate size, S9R binder (according to Austroads ATS3110 classification, approximately 9% of CR by weight of the binder) was used for the project. The mix also included 2.5% recycled crushed glass (2.5%GS), 20% RAP, and a warm mix asphalt additive (Sasobit). The addition of a warm mix asphalt additive was recommended by the AfPA project guidelines to reduce the production and compaction temperatures. All the materials used in this project were defined based on the indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and material.

The fine and coarse aggregate proportions were slightly dissimilar for the asphalt surface mixes due to the incorporation of RAP and recycled glass sand in the CRM asphalt mix. The bitumen/binder content was 6.1% bitumen by total weight of the mix for the conventional asphalt and 5.7% binder content for the CRM asphalt.
It was estimated by the contractor that approximately 10 TT and 40 PT were recycled and used in this project as CR (#30 mesh).

4.5.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over three days, one for the deep lifts and one each for the wearing courses. Specifically, the deep lift areas were paved on the 21st of June 2023, the conventional asphalt mix was paved on the 23rd of June 2023, whereas the CRM mix was laid on the 22nd of June 2023.
The distance from Boral's asphalt plant to the construction site was approximately 33.5 km. After traffic management was in place, the profiler milled the road surface and a SAMIprime K2 or CRS60 tack coat were applied after sweeping, where applicable. The rate of application was 1.0 L/m^2 and 0.3 L/m^2 for the K2 prime and CRS60 tack coat, respectively. Asphalt paving operations continued as per usual procedure using a Vogele 5200 paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums).
According to the paving records supplied by the contractor, approximately 300 tonnes (deep lift) and 127 tonnes (wearing course) of conventional asphalt, and 101 tonnes of CRM asphalt were produced. Overall, approximately 1624 m^2 of The Circle were paved using conventional asphalt, whereas approximately 1275 m^2 were paved using CRM asphalt.
The contractor did not report of any issues occurring during the paving operations in Narraweena, nor of any complaints due to asphalt fumes.

4.5.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 30th of July 2023, approximately one month after construction. The same measurements were conducted on the 11th of January 2024, approximately 6 months after initial construction, and on the 25th of July 2024, approximately 12 months after initial construction.

The outcome of the three monitoring runs are shown in Figure 22 to Figure 24. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. This particular road had the lowest traffic amongst all the SSROC projects, i.e. 1,000 vpd.

Figure 22 to Figure 24 are related to the traffic direction that goes from Oceana St. towards Victor Rd.

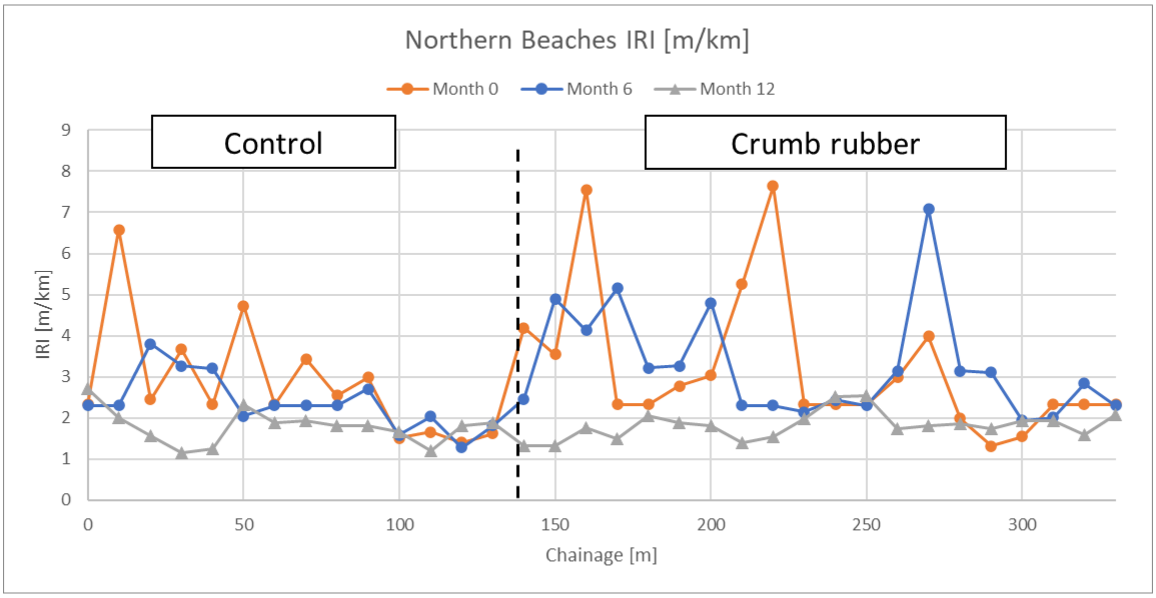


Figure 22 Evolution of the International Roughness Index (IRI, m/km) at Northern Beaches Council over 12 months

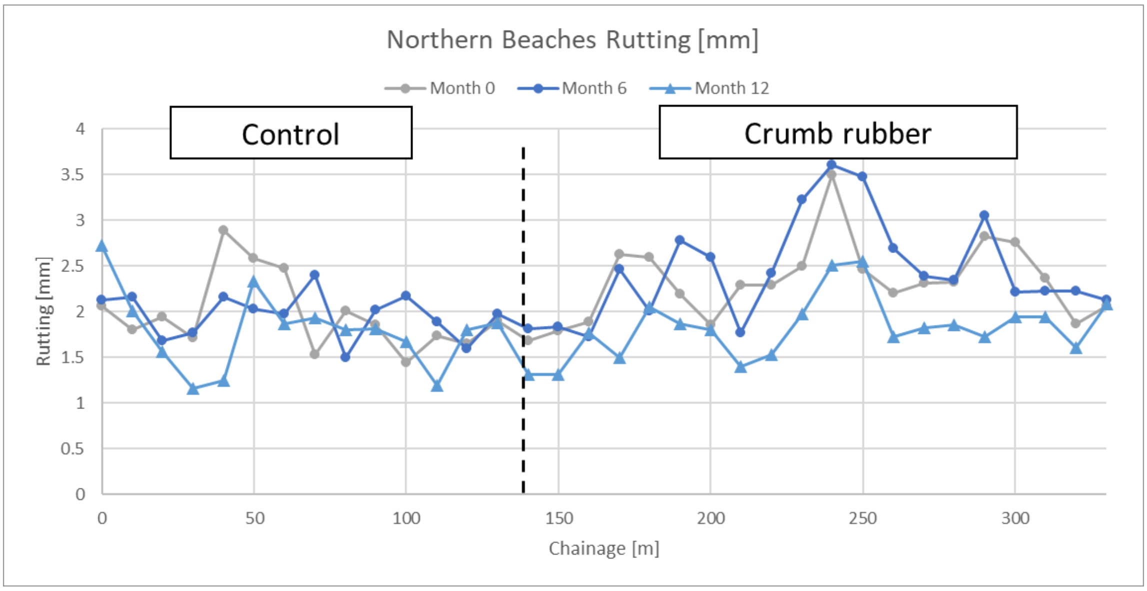


Figure 23 Evolution of rutting depth (mm) at Northern Beaches Council over 12 months

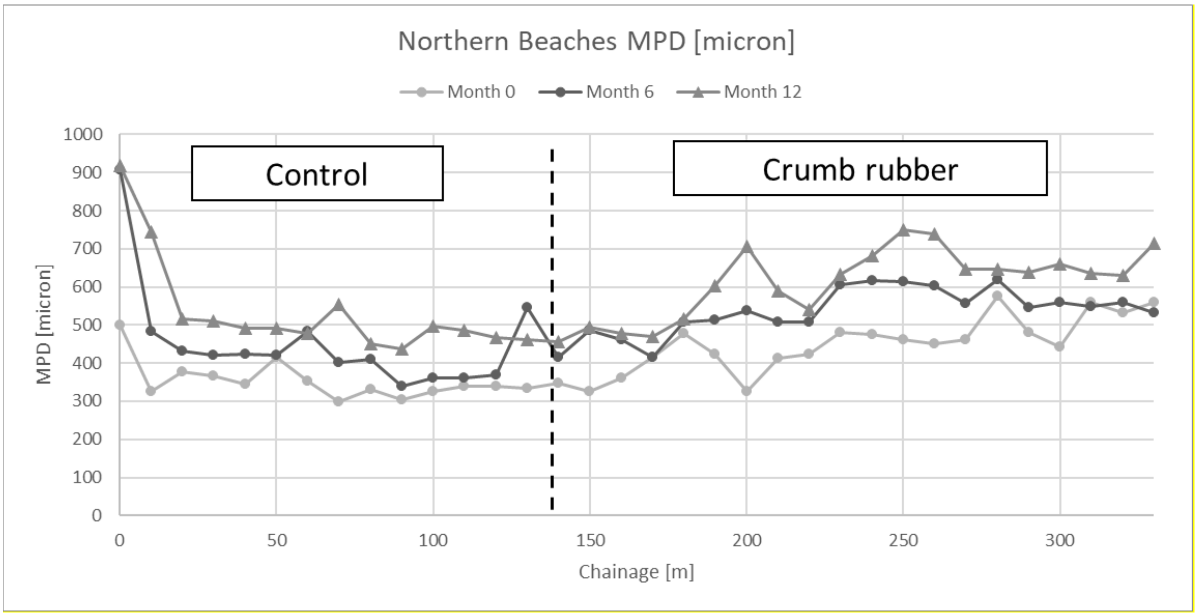


Figure 24 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at Northern Beaches Council over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- The evolution of IRI over time suggests that IRI values have reduced after 12 months. For some reason, most of the road irregularities captured during the first survey have not been measured after 12 months. It should be noted that the IRI is expected to increase over time due to the road deterioration. However, other external factors might have affected the IRI measurement in an urban environment, such as continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc.
  In general, average values of IRI between 3.5 m/km and 4 m/km are in the mid-high range for a road that has been resurfaced within 12 months. On average, the CRM asphalt section provides a smoother ride to users although the variability of the IRI values throughout the road makes the two sections similar.
- The average rutting depth after 12 months was similar in both sections. No reduction in average rutting depth was observed at locations where CR is used in the asphalt mix. It should be noted that the rutting depth is minimal at both sites due to very low traffic levels.
- Interestingly, the macrotexture of the road section where CRM asphalt was used is higher, on average, than in the control section. Although this outcome might suggest that the use of CR (wet method) can positively affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.), other road sections within the SSROC project do not seem to confirm nor deny this finding. The differences in aggregate gradation between the conventional and CRM asphalt mixes and the lower bitumen content in the CRM asphalt might have played a role in the macrotexture results.

Refer to Table 7 and Figure 25 for a detailed analysis of the trends observed.

Table 7 Average values of IRI, rutting depth, and macrotexture at Northern Beaches Council

	Control	St.dev.	Crumb rubber	St.dev.
Average IRI [m/km]	4.1	2.4	3.6	1.7
Average Rutting depth [mm]	1.8	0.4	1.8	0.3
Average MPD [micron]	530.7	129.7	619.4	85.7

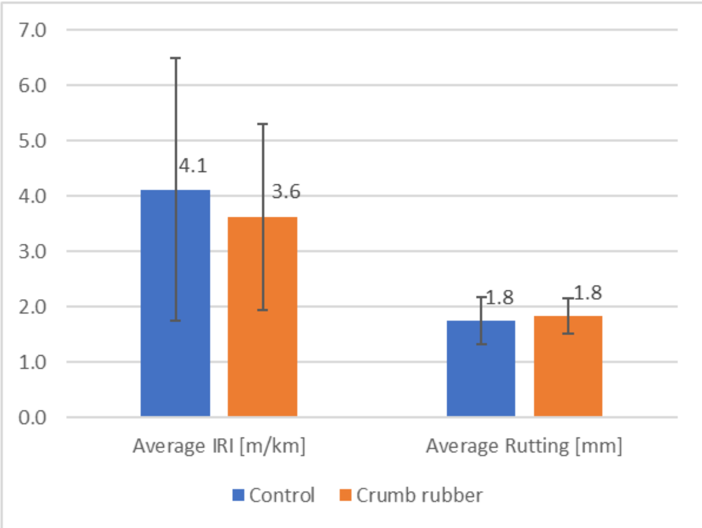


Figure 25 Average values of IRI, rutting depth, and macrotexture at Northern Beaches Council

4.6 Sutherland Shire Council, Dudley Ave

4.6.1 Project Site description

Paving operations at Sutherland Shire Council were conducted on Dudley Ave in June 2023 by Boral Asphalt NSW. Dudley Ave is located in the southern suburb of Caringbah in Sydney, New South Wales (Figure 26). It runs West-East from Port Hacking Rd to Saunders Bay Rd in Caringbah.

Initially, the council had indicated Port Hacking Rd. as the preferred project site. However, the project location had to be changed to Dudley Ave after some internal discussions.

Dudley Ave presented signs of heavy cracking, including fatigue cracking, and localised settlements. An asphalt mill and fill intervention (40 mm) was planned by the Council. Additionally, a SAMI seal treatment was applied to address some of the underlying the pavement distresses. Two different asphalt mixes were laid, a conventional dense graded asphalt mix and a dense graded CRM asphalt mix (wet method) with approximately 15% of CR by weight of the binder.

Figure 26 Project site at Sutherland Shire Council. The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.6.2 Materials and Mix design

The conventional asphalt mix was identified by the contractor with the acronym DG10 C320 AUSPEC 2.5%GS, meaning that a dense graded asphalt mix (DG), 10 mm nominal maximum aggregate size, C320 bitumen, was used for the project. Additionally, 2.5% recycled crushed glass (2.5%GS) was also incorporated into the asphalt mix as partial sand replacement.

The CRM asphalt mix was identified by the acronym DG10 S45R Sasobit 2.5%GS, meaning that a dense graded mix (DG), 10 mm nominal maximum aggregate size, S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder) was used for the project. The mix also included 2.5% recycled crushed glass (2.5%GS) and a warm mix asphalt additive (Sasobit). The addition of a warm mix asphalt additive was recommended by the AfPA project guidelines to reduce the production and compaction temperatures. All the materials used in this project were identified based on the indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and source of material.

The fine and coarse aggregate proportions were similar for both mixes, so was the bitumen/binder content; 6.1% bitumen by total weight of the mix for the conventional asphalt and 6.1% binder content for the CRM asphalt.

It was estimated by the contractor that approximately 22 TT and 96 PT were recycled and used in this project as CR (#30 mesh).

4.6.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over one day (26th of June 2023) due to the small size of the construction site.

The distance from Boral's asphalt plant to the construction site was approximately 20.8 km. After traffic management was in place, the profiler milled the road surface and various treatments were applied depending on the condition of the road. Specifically, a 10 mm SAMI seal was applied after milling to waterproof the pavement and attempting to avoid any possible reflection of distresses from deeper layers to the upper layer. Asphalt paving operations continued as per usual procedure using a Vogele 5200 paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums).

According to the paving records supplied by the contractor, approximately 150 tonnes of conventional asphalt and 115 tonnes of CRM asphalt were produced. Overall, approximately 1253 m^2 of Dudley Ave were paved using conventional asphalt, whereas approximately 1224 m^2 were paved using CRM asphalt.

The contractor did not report of any issues occurring during the paving operations at Dudley Ave, nor of any complaints due to asphalt fumes.

4.6.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 27th of July 2023, approximately one month after construction. The same measurements were conducted on the 10th of January 2024, approximately 6 months after initial construction, and on the 10th of July 2024, approximately 12 months after initial construction.

The outcome of the three monitoring runs are shown in Figure 27 to Figure 29. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).

Figure 27 to Figure 29 are related to the traffic direction that goes from Port Hacking St towards Saunders Bay Rd.

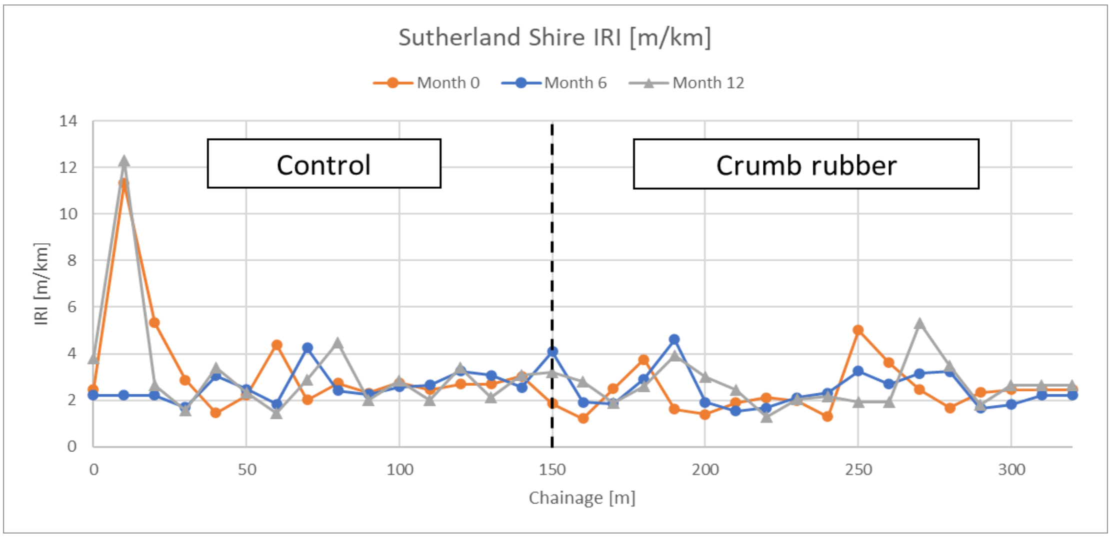


Figure 27 Evolution of the International Roughness Index (IRI, m/km) at Sutherland Shire Council over 12 months

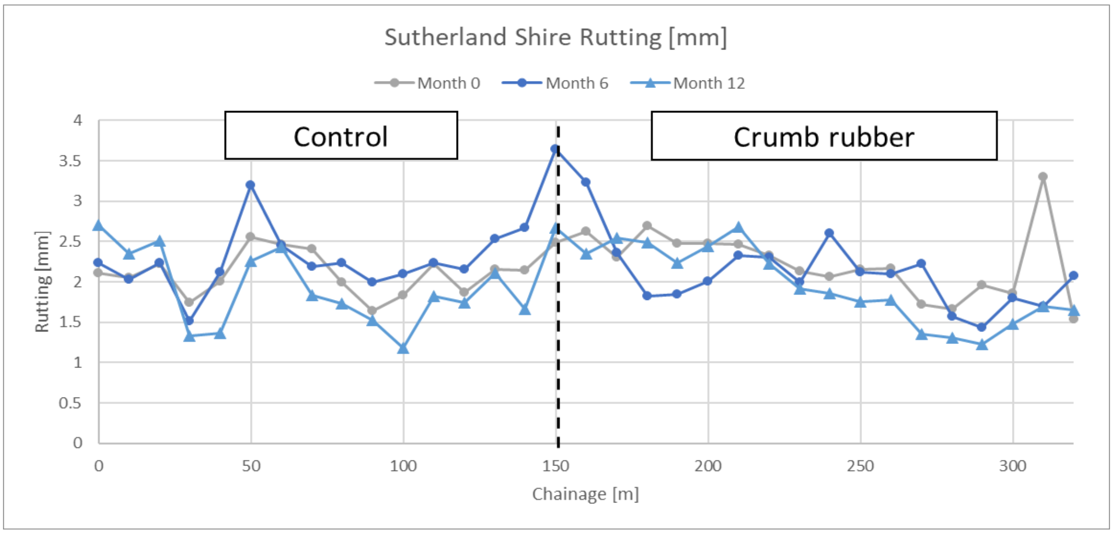


Figure 28 Evolution of rutting depth (mm) at Sutherland Shire Council over 12 months

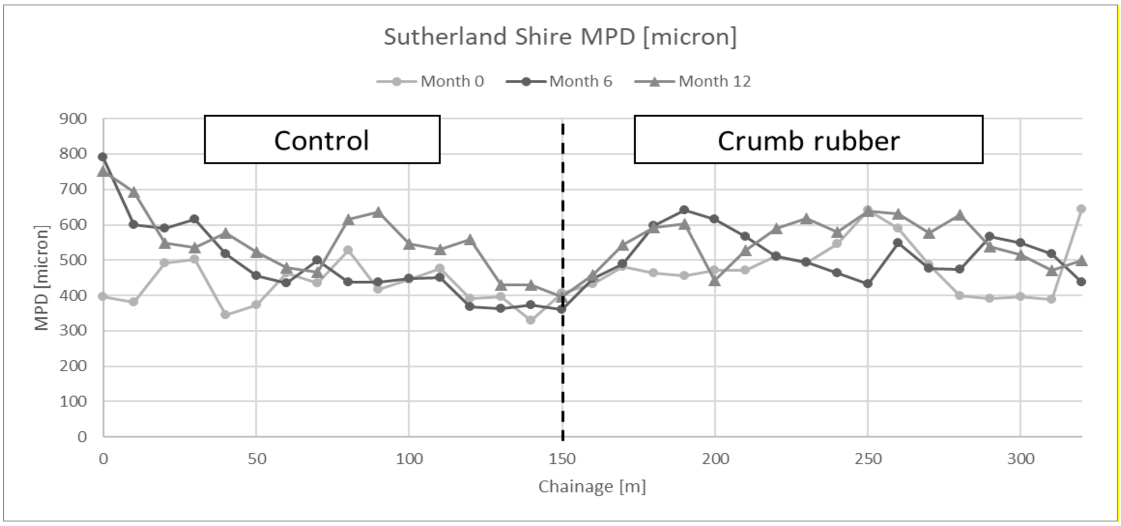


Figure 29 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at Sutherland Shire Council over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses can evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed on the evolution of IRI over time; the three sets of measurements at 1-6-12 months are largely consistent. In general, average values of IRI between 2.5 m/km and 3.5 m/km are in the mid-range for a road that has been resurfaced within 12 months. Other external factors might have affected the IRI measurement in an urban environment, such as continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc. Construction operations might have also contributed to slight differences in IRI. On average, the CRM asphalt section provides a smoother ride to users although the variability of the IRI values throughout the entire stretch of road makes the two sections similar.
- The average rutting depth after 12 months was similar in both sections. No major reduction in average rutting depth was observed at locations where a CRM asphalt mix is used.

- No major changes were observed in the macrotexture of the road. The use of CR (wet method) does not seem to affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.).

Refer to Table 8and Figure 30 for a detailed analysis of the trends observed.

Table 8 Average values of IRI, rutting depth, and macrotexture at Sutherland Shire Council

	Control	St.dev.	Crumb rubber	St.dev.
Average IRI [m/km]	3.3	2.52	2.6	0.95
Average Rutting depth [mm]	2.0	0.49	1.9	0.47
Average MPD [micron]	544.9	96.44	555.5	62.53

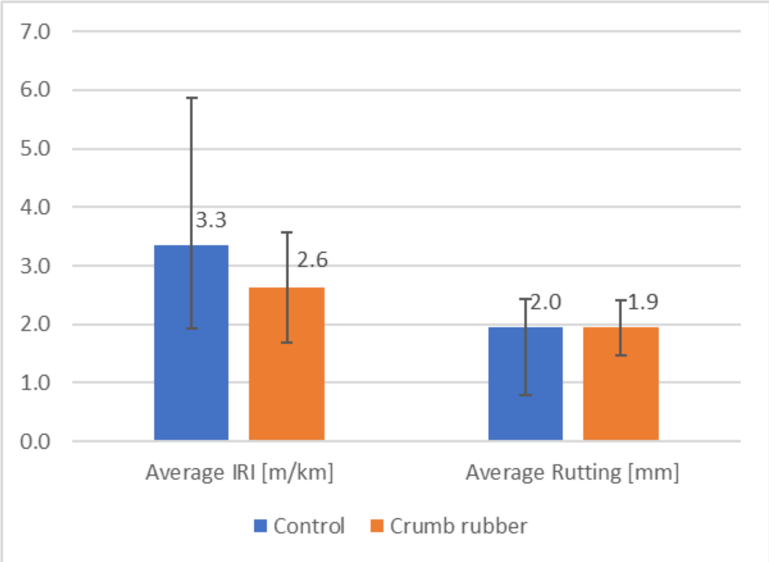


Figure 30 Average values of IRI, rutting depth, and macrotexture at Sutherland Shire Council

4.7 Inner West Council, Hutchinson St

4.7.1 Project Site description

Paving operations at Inner West Council were conducted at Hutchinson St in June 2023 by Boral Asphalt NSW. Hutchinson St is located in the western inner suburbs of Sydney, New South Wales (Figure 31). Hutchinson St is a local residential road that runs from Railway Parade to Annandale St in Annandale. The project aimed at carrying out maintenance to improve the status of the aged pavement surface.

Initially, the council had indicated Westbourne St as the preferred project site. However, the project location was eventually changed to Hutchinson St. It is not known to the authors what drove this decision and what the pavement distresses were in Hutchinson St prior to resurfacing.

The Council planned a standard maintenance intervention that included asphalt milling and filling (40 mm) to address the pavement distresses. Two different asphalt wearing course mixes were laid: a conventional dense graded asphalt mix and a dense graded CRM asphalt mix (wet method) with approximately 9% of rubber by weight of the binder.

Figure 31 Project site at Inner West Council. The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.7.2 Materials and Mix design

The conventional asphalt mix was identified by the contractor with the acronym DG10 C320 2.5%GS, thus indicating a dense graded asphalt mix (DG), 10 mm nominal maximum aggregate size, C320 bitumen, 2.5% recycled crushed glass (2.5%GS) as partial sand replacement. The CRM asphalt mix was identified by the acronym DG10 S9R Sasobit, indicating a dense graded mix (DG), 10 mm nominal maximum aggregate size, S9R binder (according to Austroads ATS3110 classification, approximately 9% of CR by weight of the binder) was used for the project. The mix also included a warm mix asphalt additive (Sasobit). The addition of a warm mix asphalt additive was recommended by the AfPA project guidelines to reduce the production and compaction temperatures. All the materials used in this project were defined based on the indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and material.

The fine and coarse aggregate proportions were similar for both mixes, so was the bitumen/binder content; 6% bitumen by total weight of the mix for the conventional asphalt and 5.9% binder content for the CRM asphalt. Small differences between plant-produced batches should be expected.

It was estimated by the contractor that approximately 131 TT and 33 PT were recycled and used in this project as CR (#30 mesh).

4.7.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over one day due to the small size of the project. Specifically, the conventional asphalt and CRM asphalt were paved on the 27th of June 2023.

The distance from Boral's asphalt plant to the construction site was approximately 15.7 km. After traffic management was in place, the profiler milled the road surface and a SAMIprime K2 or CRS60 tack coat were applied after sweeping where applicable. The rate of application was 1.0 L/m2 and 0.3 L/m2 for the K2 prime and CRS60 tack coat, respectively. Asphalt paving operations continued as per usual procedure using a Vogele 5200 paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums).

According to the paving records supplied by the contractor, approximately 115 tonnes of conventional asphalt and 140 tonnes of CRM asphalt were produced on that day. Overall, approximately 1212 m2 of Hutchinson St were paved using conventional asphalt, whereas approximately 1430 m2 were paved using CRM asphalt.

The contractor did not report of any issues occurring during the paving operations in Annandale, nor of any complaints due to asphalt fumes.

4.7.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. Due to unknown circumstances, the survey was conducted at a different location (Westbourne St) from the one identified by the council. Therefore, no monitoring data is available for Inner West Council. Council engineers are recommended to visit the site regularly and run at least a visual assessment every six months.

4.8 City of Sydney, Sussex St

4.8.1 Project Site description

Paving operations at the City of Sydney were conducted on Sussex St (Haymarket) in June 2023 by Boral Asphalt NSW. Sussex St is in the central business district of Sydney in New South Wales (Figure 32). It runs north-south along the western side of the city centre, between Hickson Rd. and Hay St.

The works included a conventional mill & fill (50 mm) using two asphalt mix designs: a conventional dense graded asphalt mix and a dense graded CRM asphalt mix.

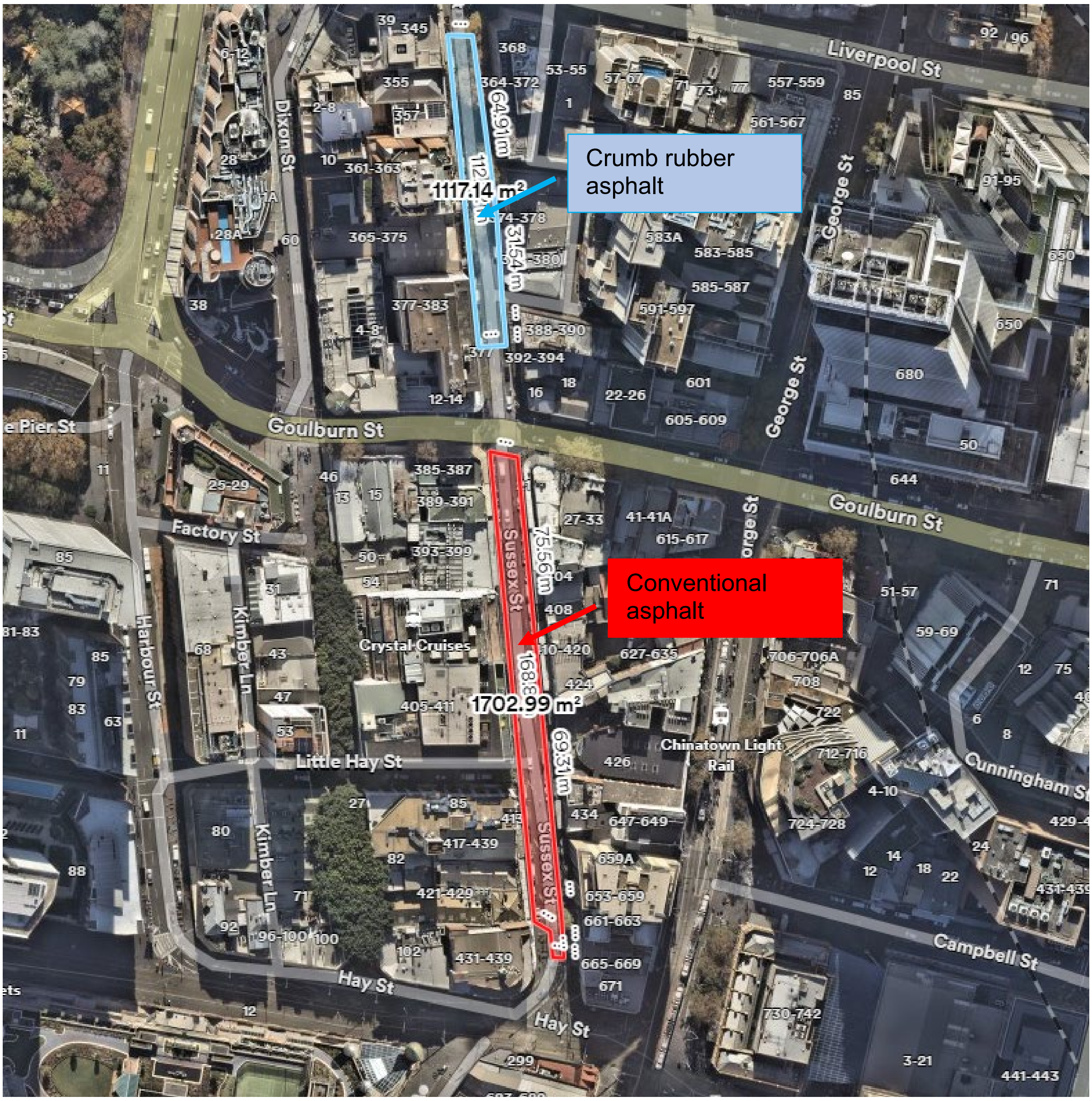


Figure 32 Project site at the City of Sydney. The light blue hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.8.2 Materials and Mix design

The conventional asphalt mix was identified by the contractor with the acronym DG14 C450 HD 2.5%GS, which indicates that a dense graded asphalt mix (DG), 14 mm nominal maximum aggregate size, C450 bitumen, and 'heavy duty' (HD) asphalt was used for the project. Additionally, 2.5% recycled crushed glass (2.5%GS) was incorporated into the asphalt mix as partial sand replacement.

The CRM asphalt mix was identified by the acronym DG14 S45R SAS 2.5%GS, indicating that a dense graded asphalt mix (DG), 14 mm nominal maximum aggregate size, S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder) was used for the project. The mix also included 2.5% recycled crushed glass (2.5%GS) and a warm mix asphalt additive (SAS, e.g. Sasobit). The addition of a warm mix asphalt additive was recommended by the AfPA project guidelines to reduce the production and compaction temperatures. All the materials used in this project were identified based on the indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and source of material.

The fine and coarse aggregate proportions were similar for both mixes, so was the bitumen/binder content; 5.2% bitumen by total weight of the mix for the conventional asphalt and 5.3% binder content for the CRM asphalt. A minimum tolerance should always be accounted for at the production plant.

It was estimated by the contractor that approximately 87 TT and 22 PT were recycled and used in this project in the form of CR (#30 mesh).

4.8.3 Paving Operations

Paving operations were carried out by Boral Asphalt NSW over four days to minimise traffic disruptions in the area and issues to shops and users. Specifically, the conventional asphalt mix was laid on the 21st and 27th of June 2023, whereas the CRM mix was laid between the 28th and 29th of June 2023.

The distance between the asphalt plant and the construction site was approximately 19.5 km. After traffic management was in place, the profiler milled the road surface and a SAMIprime K2 or CRS60 tack coat were applied after sweeping, where applicable. The rate of application was 1.0 L/m^2 and 0.3 L/m^2 for the K2 prime and CRS60 tack coat, respectively. Asphalt paving operations continued as per the usual procedure using a Roadtek RP175EX paver and three rollers: Hamm HD70 (steel tandem roller with two vibrating drums), Dynapac CP142 (pneumatic tyred roller, 6 tonnes), and Hamm HD10C (compact tandem roller with two vibrating drums).

According to the paving records supplied by the contractor, approximately 116.6 tonnes of asphalt (conventional asphalt) were produced and laid on the 21st of June 2023, 102.4 tonnes (conventional asphalt) on the 27th of June 2023, and 117.2 tonnes (CRM asphalt) between the 28th and 29th of June 2023. Overall, approximately 1703 m^2 of Sussex St were paved using conventional asphalt, whereas approximately 1117 m^2 were paved using CRM asphalt.

The contractor did not report of any issues occurring during the paving operations at Sussex St, nor of any complaints due to asphalt fumes.

4.8.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting depth, and macrotexture values were first assessed on the 30th July 2023, approximately one month after construction. The same measurements were conducted on the 13th of January 2024, approximately 6 months after the initial construction, and on the 11th of July 2024, approximately 12 months after the initial construction.

The outcome of the three monitoring runs are shown in Figure 33 to Figure 35. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).

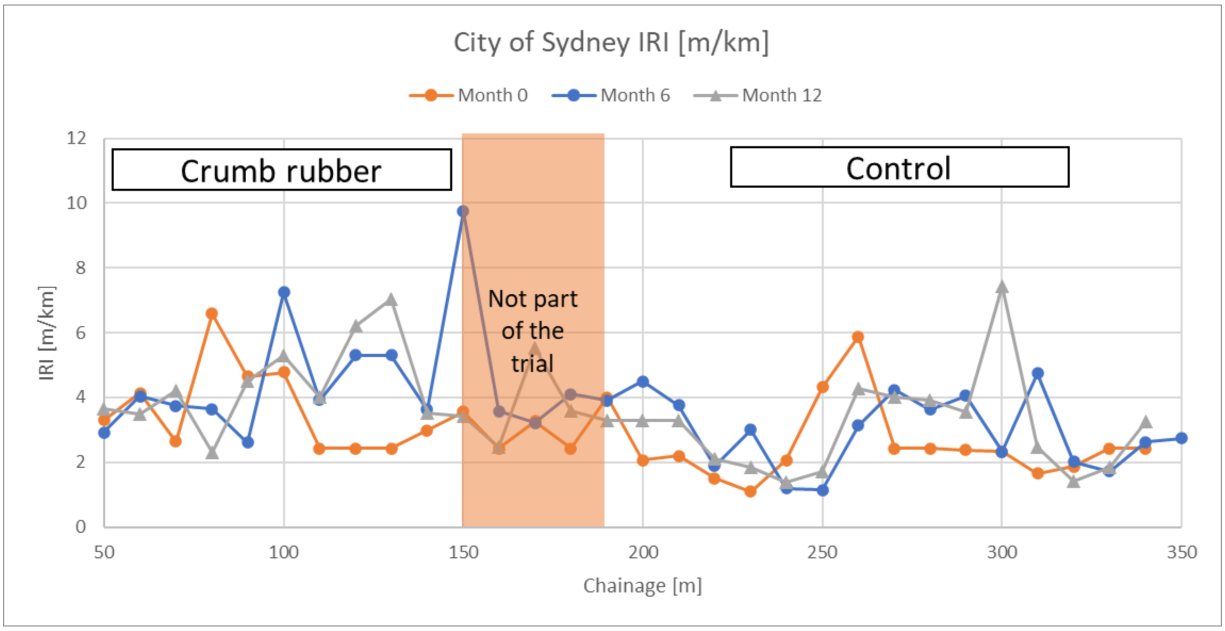


Figure 33 Evolution of the International Roughness Index (IRI, m/km) at City of Sydney over 12 months. The hatched area identifies a location in the proximity of the intersection between Sussex St. and Goulbourn St. which was not part of the monitoring.

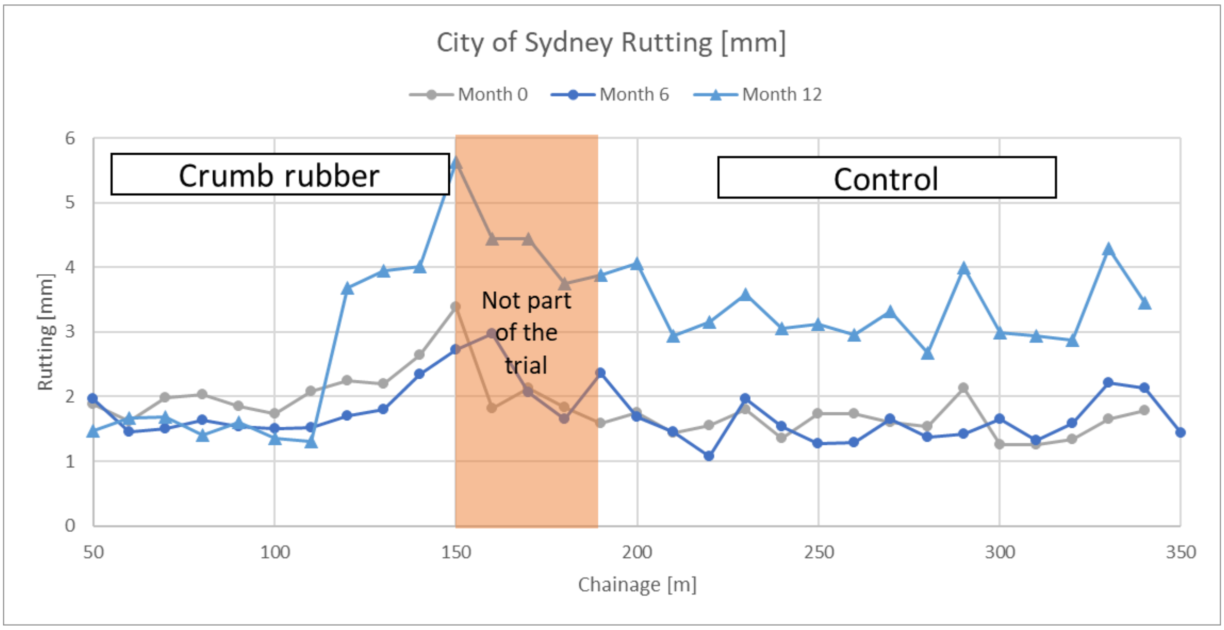


Figure 34 Evolution of rutting depth (mm) at City of Sydney over 12 months. The hatched area identifies a location in the proximity of the intersection between Sussex St. and Goulbourn St. which was not part of the monitoring.

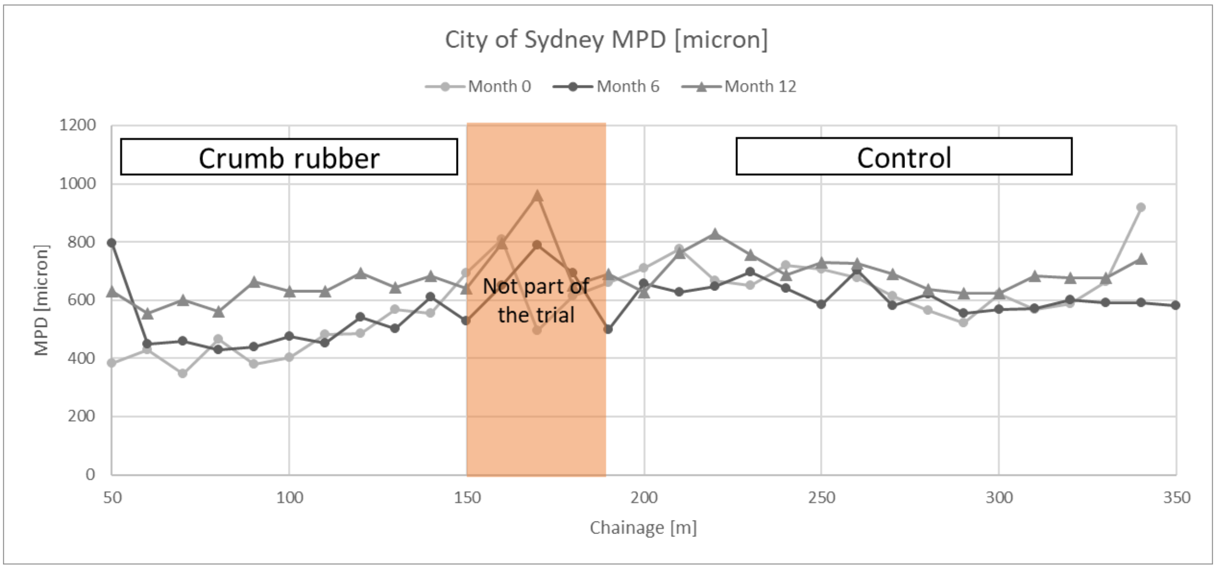


Figure 35 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at City of Sydney over 12 months. The hatched area identifies a location in the proximity of the intersection between Sussex St. and Goulbourn St. which was not part of the monitoring.

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since several pavement distresses can evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed for the evolution of IRI values over time. In general, average values of IRI of 3.1 m/km (control section) and 4.4 m/km (CR section) are in the mid to high range for a road that has been resurfaced within 12 months. Other external factors might have affected the IRI measurement in the CBD of Sydney, including continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, intersections, etc. Construction operations might have also contributed to slight differences in IRI. On average, the conventional asphalt section provides a smoother ride to users.
- The average rutting depth across the CRM asphalt section was 2.2 mm, compared to 3.3 mm of the control section. This shows approximately 33% reduction in rutting depth over the first 12 months when CR is used in the asphalt mix.
- No major changes were observed in the macrotexture of the road. The use of CR(wet method) does not seem to affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.).

Refer to Table 9 and Figure 36 for a detailed analysis of the trends observed.

Table 9 Average values of IRI, rutting depth, and macrotexture at City of Sydney

	Control	St.dev.	Crumb rubber	St.dev.
Average IRI [m/km]	3.1	1.51	4.4	1.41
Average Rutting depth [mm]	3.3	0.49	2.2	1.16
Average MPD [micron]	697.3	57.22	628.9	46.50

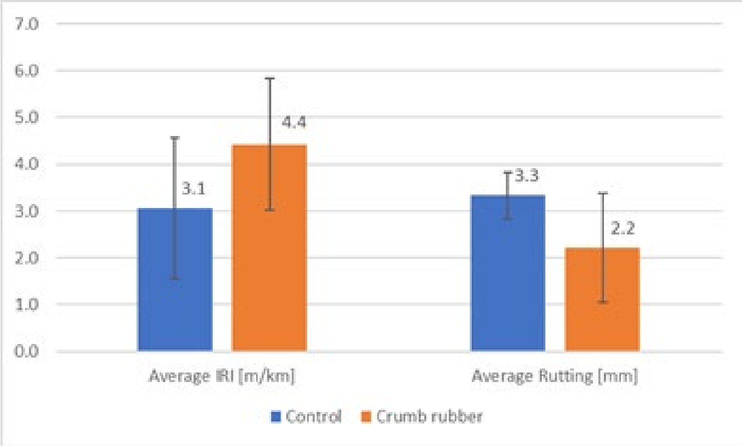


Figure 36 Average values of IRI, rutting depth, and macrotexture at City of Sydney

4.9 City of Canada Bay, Cabarita Rd

4.9.1 Project Site description

Paving operations at the City of Canada Bay were conducted on Cabarita Rd in June 2023 by Fulton Hogan NSW. Cabarita Rd is located between the CBD of Sydney and Paramatta in New South Wales (Figure 37). It runs North-South from Cabarita Park towards France Bay. The section of Cabarita Rd. which was due for resurfacing stretched from Medora Lane to the park access gate.

The poor conditions of the road, mostly due to heavy bus traffic, showed crocodile cracking and rutting. Therefore, the Council planned for a thicker than usual (60 mm) mill and fill intervention. Two different asphalt mix designs were laid side-by-side (i.e. one on each traffic lane). This choice considers that the same volume of traffic enters and exits through the park access gate due to the site's specific layout. A conventional dense graded asphalt mix and a dense graded CRM asphalt mix (wet method) with approximately 15% of rubber by weight of the binder were used in this project.

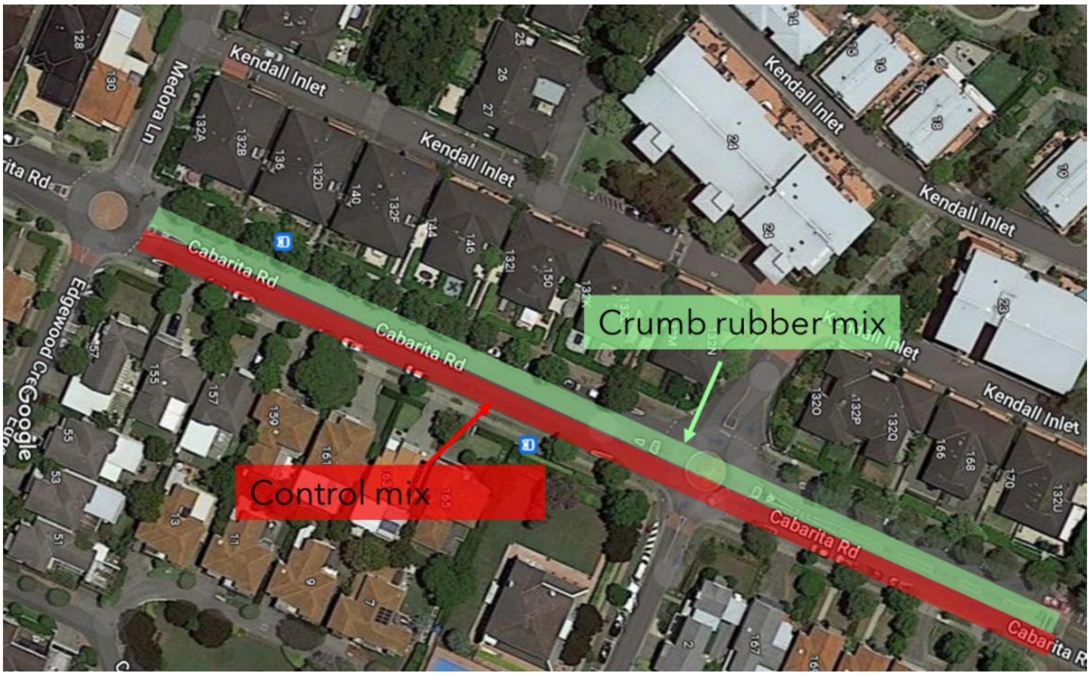


Figure 37 Project site at the City of Canada Bay. The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.9.2 Materials and Mix design

The conventional asphalt mixes for the asphalt wearing course were classified by the contractor as DG14 C320 and DG14 TYREPHALT, respectively. The first mix was a conventional asphalt mix, dense graded, 14 mm nominal maximum aggregate size, C320 bitumen. No recycled crushed glass as sand replacement nor RAP were used in this mix design. The second asphalt mix was wet process dense graded CRM (medium content); 14 mm nominal maximum aggregate size, S15R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder). Similar to the conventional mix, no recycled crushed glass as sand replacement nor RAP were used in this mix design. No warm mix asphalt additive was used in this project.

All the materials used in this project were identified based on the technical indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and source of material.

The fine and coarse aggregate proportions were similar for the two surface asphalt mixes, so was the bitumen (or binder) content; 5.2% binder content for the CRM asphalt at 15% rubber, and 5.1% binder content for the conventional asphalt. A minimum tolerance should always be accounted for at the production plant. The primary source to produce CR was a combination of TT and PT.

4.9.3 Paving Operations

Paving operations were carried out by Fulton Hogan NSW in one day, the 16th of June 2023. The distance from the asphalt plant (Eastern Creek) to the construction site was approximately 34 km. A tack coat was applied after milling and sweeping, where applicable, at a rate of 0.25 L/m^2.

According to the paving records supplied by the contractor, approximately 195.76 tonnes of DG14 C320 asphalt (conventional asphalt) were produced and laid, in comparison to 185.16 tonnes of DG14 Tyrephalt (CRM asphalt). Overall, approximately 2482 m^2 of Cabarita Rd were paved using conventional asphalt, and a similar area was covered for the CRM asphalt section.

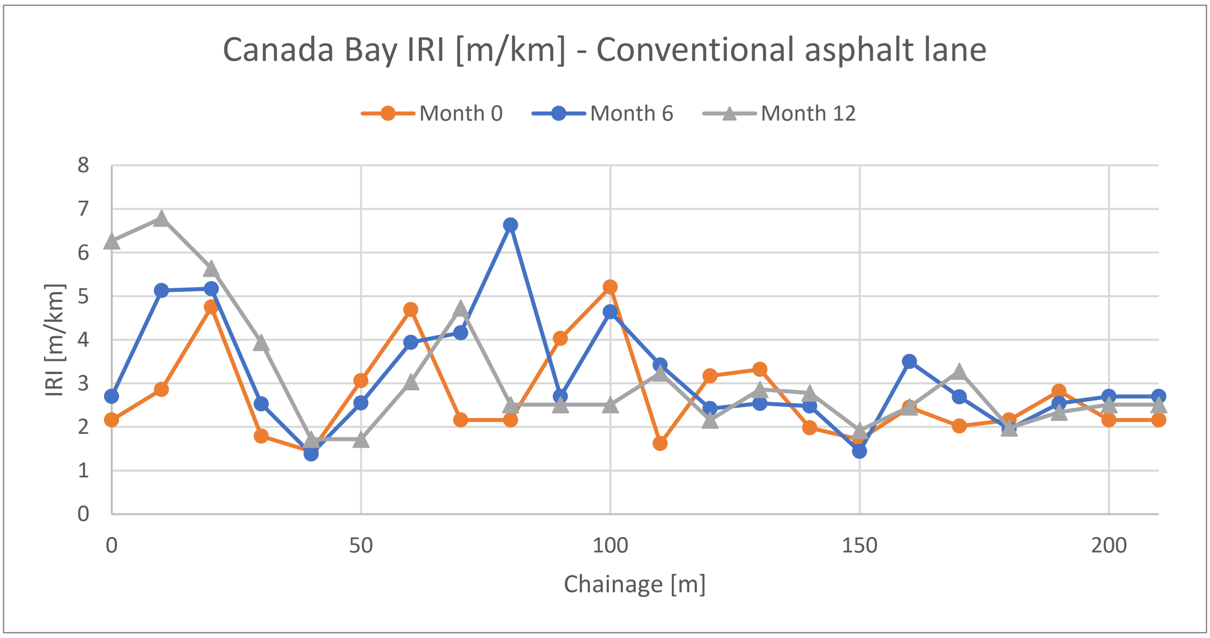
The contractor did not report of any issues occurring during the paving operations, nor of any complaints due to asphalt fumes.

The air voids content was measured on-site by the contractor after one week from the paving operations via field core analysis according to AS 2891.1.2 - (7.2 - Wet) specifications, AS/NZS 2891.8, AS/NZS 2891.9.2. Results show an average voids content of 5.7% ± 1.4% for the DG14 C320 road section and 4.6% ± 0.6% for the DG14 Tyrephalt road section.

4.9.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 27th of July 2023, approximately one month after construction. The same measurements were conducted on the 11th of January 2024, approximately 6 months after the initial construction, and on the 11th of July 2024, approximately 12 months after the initial construction.

The outcome of the three monitoring runs are shown in Figure 38 to Figure 40. The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic values (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).



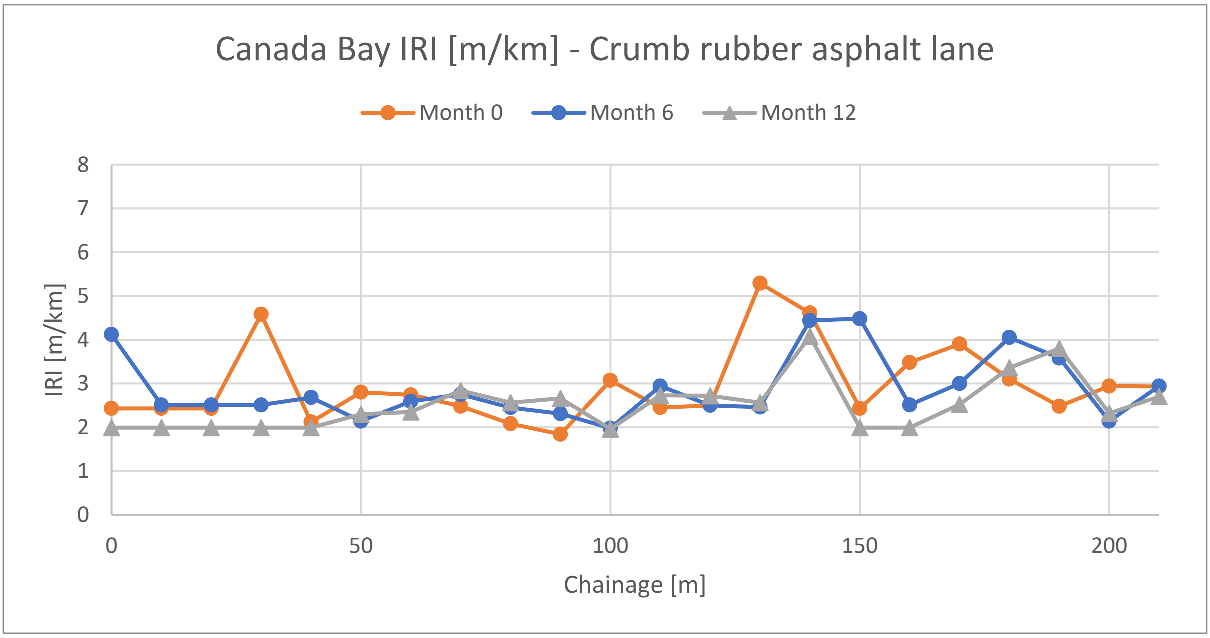
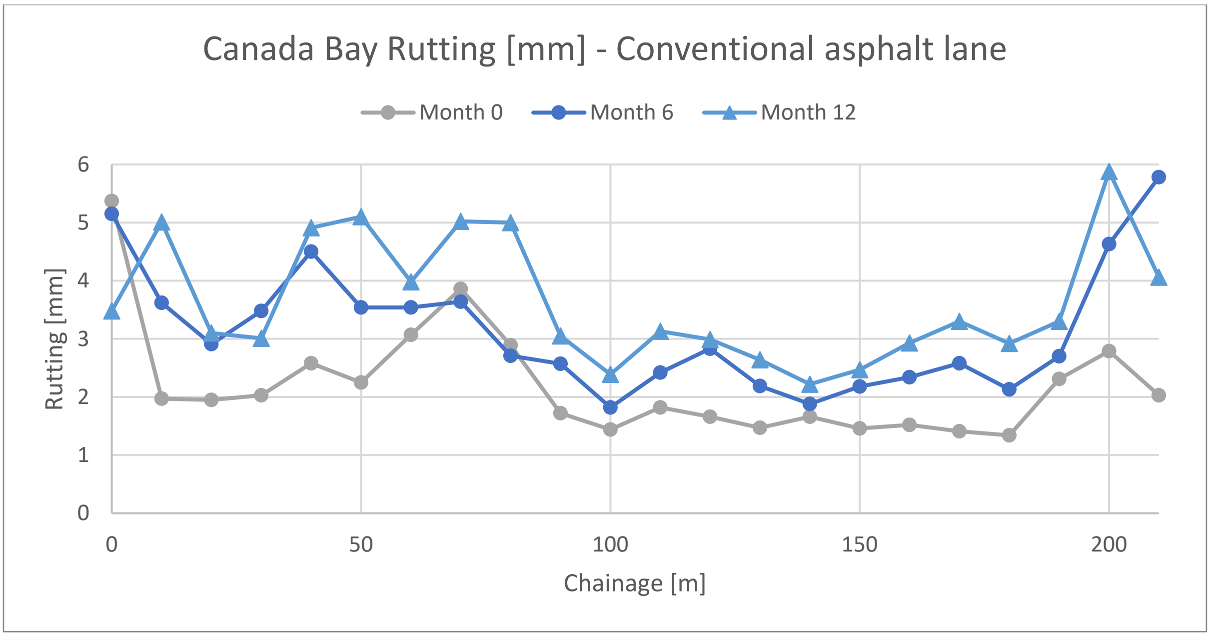


Figure 38 Evolution of the International Roughness Index (IRI, m/km) at City of Canada Bay over 12 months



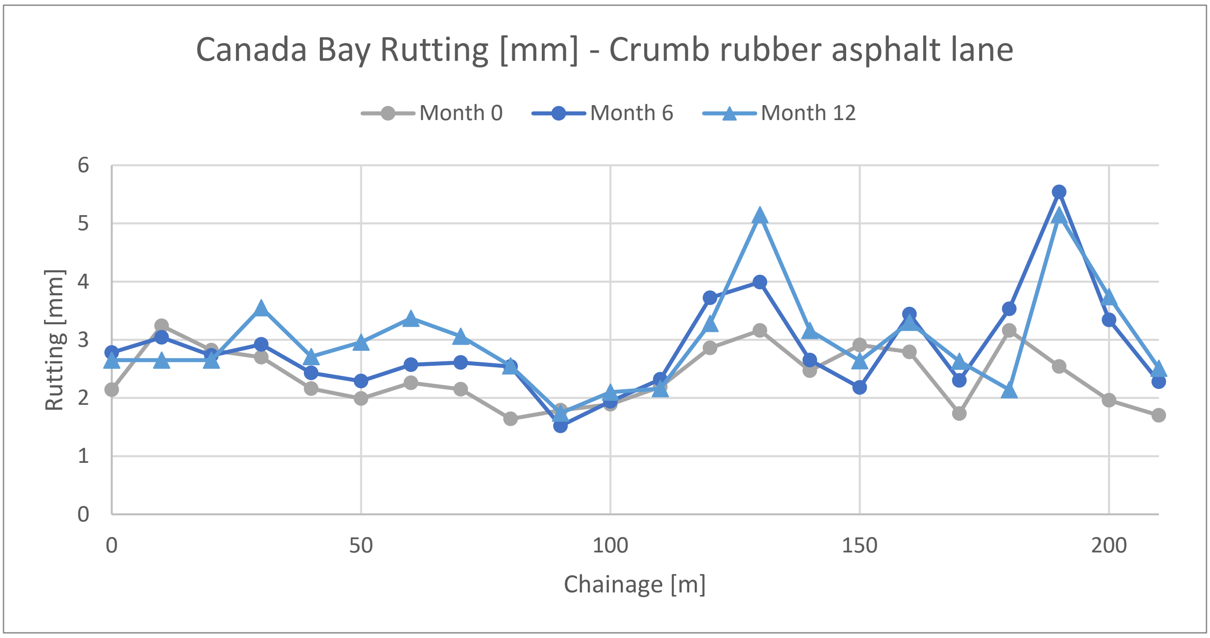


Figure 39 Evolution of rutting depth (mm) at City of Canada Bay over 12 months

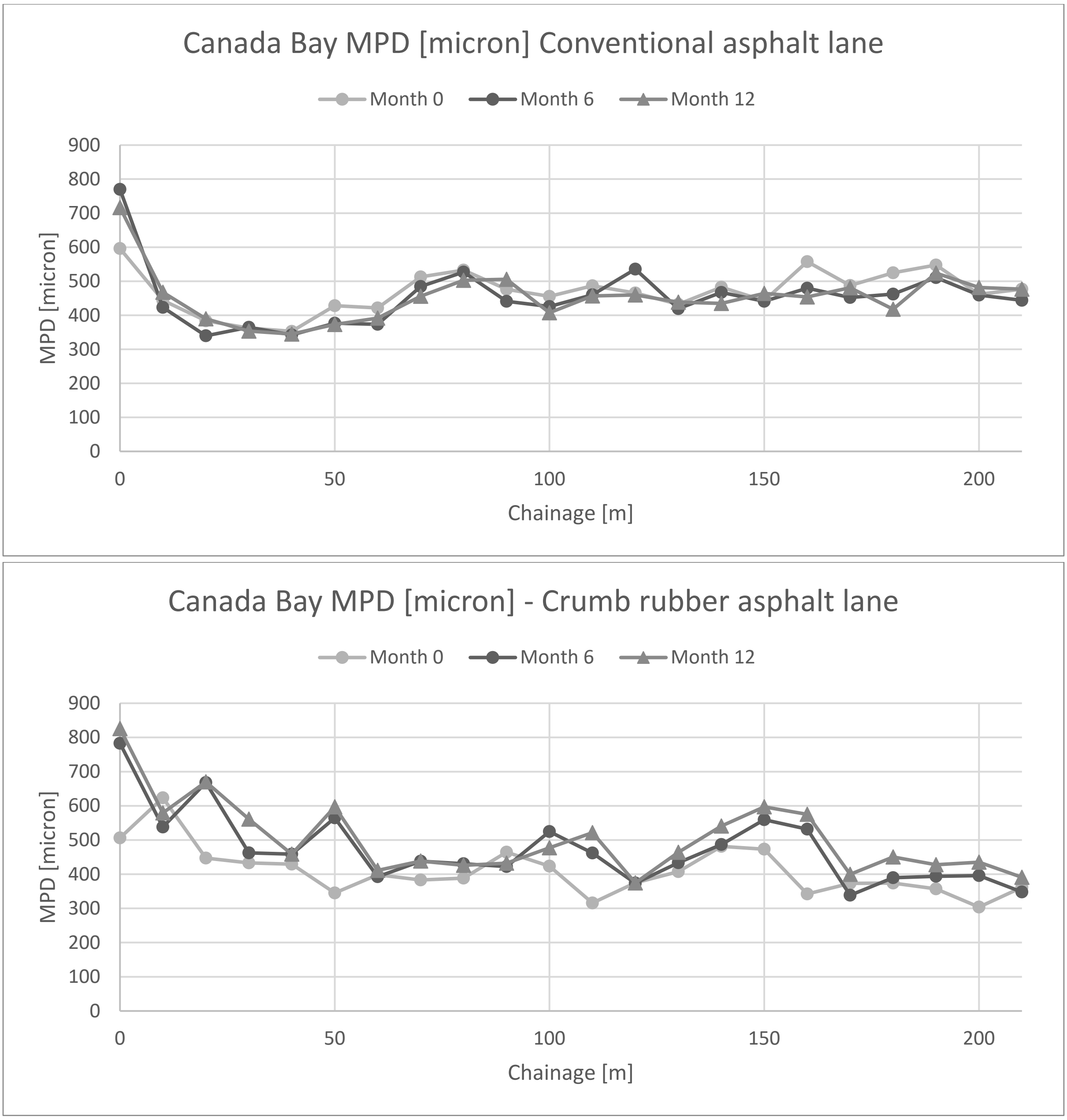


Figure 40 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at City of Canada Bay over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since pavement distresses can evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed on the evolution of IRI over time. However, the CRM asphalt section resulted in a slightly smoother road profile compared to the conventional asphalt. In general, average values of IRI between 2.5 m/km and 3 m/km are in the mid-range for a road that has been resurfaced within 12 months. Other external factors might have affected the IRI measurement, including continuous traffic stops, cars in and out of parking spots, slow moving traffic, localised utilities, presence of small roundabouts and intersections, etc. Construction operations might have also contributed to slight differences in IRI.
- The CRM asphalt section shows average rutting depth after 12 months below the value recorded for the control section. In general, approximately 17% reduction in average rutting depth was observed over the first 12 months when CR is used in the asphalt mix.

- No major changes were observed in the macrotexture of the road. The use of CR (wet method) does not seem to affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.).

Refer to Table 10 and Figure 41 for a detailed analysis of the trends observed.

Table 10 Average values of IRI, rutting depth, and macrotexture at City of Canada Bay

	Control	St.dev.	Crumb rubber 15%	St.dev.
Average IRI [m/km]	3.0	1.3	2.5	0.6
Average Rutting depth [mm]	3.6	1.1	3.0	0.9
Average MPD [micron]	440	50.6	487	83

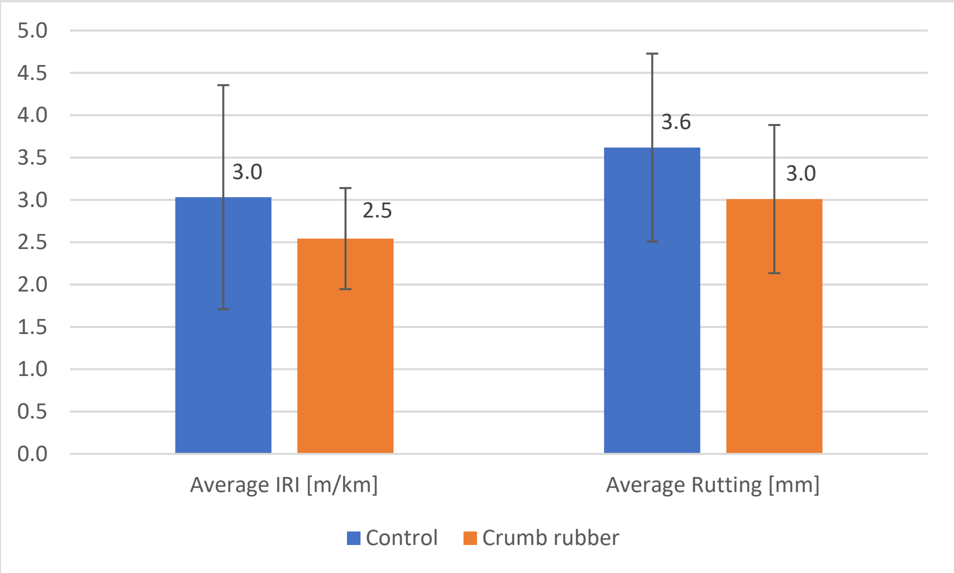


Figure 41 Average values of IRI, rutting depth, and macrotexture at City of Canada Bay

4.10 Canterbury-Bankstown City Council, Old Kent Rd

4.10.1 Project Site description

Paving operations at the City of Canterbury-Bankstown were conducted on Old Kent Rd. in August 2023 by State Asphalt NSW. Old Kent Rd is located in the western suburbs of Sydney in New South Wales (Figure 42). It runs west-east between Salamander Pl and Konrad Ave.

Due to the poor conditions of the road showing crocodile cracking and rutting, the works included a full reconstruction of both the base asphalt layer and wearing course. Despite the base course being the same material across the entire stretch of road (AC20 C320 bitumen, 60 mm), three different mix designs were used for the wearing course (40 mm): a conventional dense graded asphalt mix, a dense graded CRM asphalt mix (wet method) with approximately 9% of rubber by weight of the binder, and a dense graded CRM asphalt mix (wet method) with approximately 15% of rubber by weight of the binder.

Figure 42 Project site at the City of Canterbury-Bankstown. The light blue and green hatched areas show the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.10.2 Materials and Mix design

The conventional asphalt mix for the base layer was identified by the contractor with the acronym AC20 C320 Glass, indicating a dense graded mix, 20 mm nominal maximum aggregate size, C320 bitumen. 9.5% recycled crushed glass (as partial sand replacement) and 15% RAP were also incorporated into this asphalt mix.

The CRM asphalt mixes were identified by the acronym AC10 C320 Glass, AC10 S9R, and AC10 S45R, respectively. The first mix was a conventional asphalt mix, dense graded, 10 mm nominal maximum aggregate size, C320 bitumen, 2.4% recycled crushed glass (as partial sand replacement) and 15% RAP. The second asphalt mix was wet process dense graded CRM,10 mm nominal maximum aggregate size, S9R binder (according to Austroads ATS3110 classification, approximately 9% of CR by weight of the binder), 2.4% recycled crushed glass (as partial sand replacement) and no RAP. The third asphalt mix was a wet process dense graded CRM (medium content) , 10 mm nominal maximum aggregate size, S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder), 2.4% recycled crushed glass (as partial sand replacement) and 0% RAP. No warm mix asphalt additive was used in this project.

All the materials used in this project were defined based on the technical indications provided by AfPA although the council and the contractor jointly made the final choice of mix design and source of material.

The fine and coarse aggregate proportions were similar for all the surface asphalt mixes, so was the bitumen (or binder) content; 5.5% binder content for the CRM asphalt at 9% rubber, and 5.8% binder content for the CRM asphalt at 15% rubber. A minimum tolerance should always be accounted for at the production plant. The primary source to produce CR was TT.

4.10.3 Paving Operations

Paving operations were carried out by State Asphalt NSW over three days, from the 16th of August 2023 to 18th of August 2023. The distance from the asphalt plant to the construction site was approximately 23.1 km. A tack coat was applied after milling and sweeping, where applicable, at a rate of 0.3 L/m^2.

According to the paving records supplied by the contractor, approximately 344.26 tonnes of AC20 base layer asphalt (conventional asphalt) were produced and laid, 145.10 tonnes of AC10 wearing course asphalt (conventional asphalt), 133.54 tonnes of AC10 S9R (CRM asphalt), and 144.96 tonnes of AC10 S45R (CRM asphalt). Overall, approximately 1485 m^2 of Old Kent Rd. were paved using conventional asphalt, and a similar area was covered for each of the two CRM asphalt sections.

The contractor did not report of any issues occurring during the paving operations, nor of any complaints due to asphalt fumes.

The air voids content was measured on-site by the contractor using a Troxler Nuclear Density Gauge according to AS2891.14.2 and AS2891.14.5; the results show an average voids content of 5.9% ±1.9% for the AC10 S9R road section and 6.5% ± 1.7% for the AC10 S45R road section.

4.10.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct monitoring at the project location. The International Roughness index, rutting, and macrotexture values were first assessed on the 6th of October 2023, approximately two months after construction. The same measurements were conducted on the 10th of January 2024, approximately 5 months after the initial construction, and on the 11th of July 2024, approximately 12 months after the initial construction.

The outcome of the three monitoring runs are shown in Figure 43 to Figure 45). The authors did not receive information about the traffic volumes and its characteristics during the monitoring period although the council should have access to more specific data. In general, all the council roads which were part of the SSROC project had traffic (both ways) between 1,000 vpd (Northern Beaches) and 25,000 vpd (Woollahra).

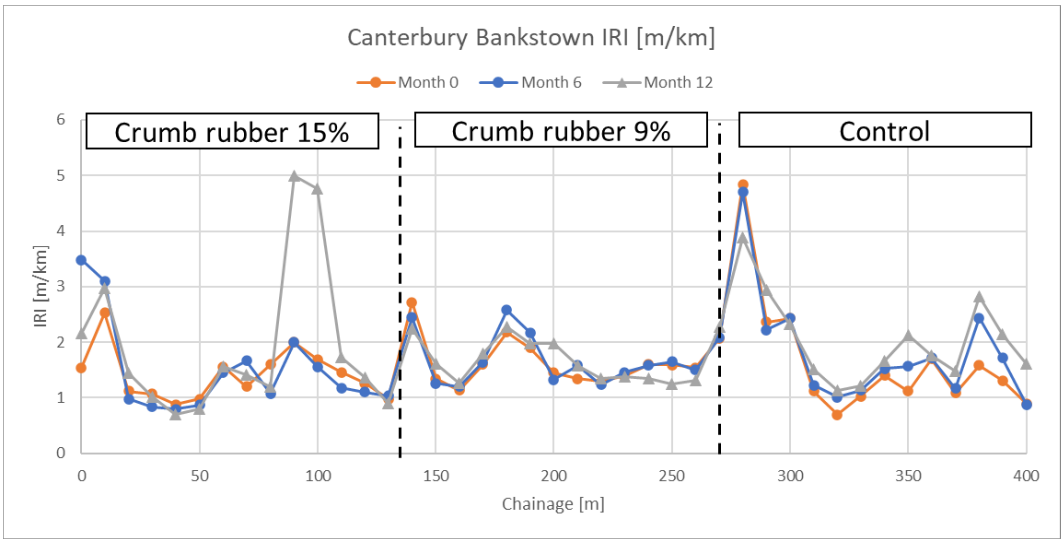


Figure 43 Evolution of the International Roughness Index (IRI, m/km) at City of Canterbury-Bankstown over 12 months

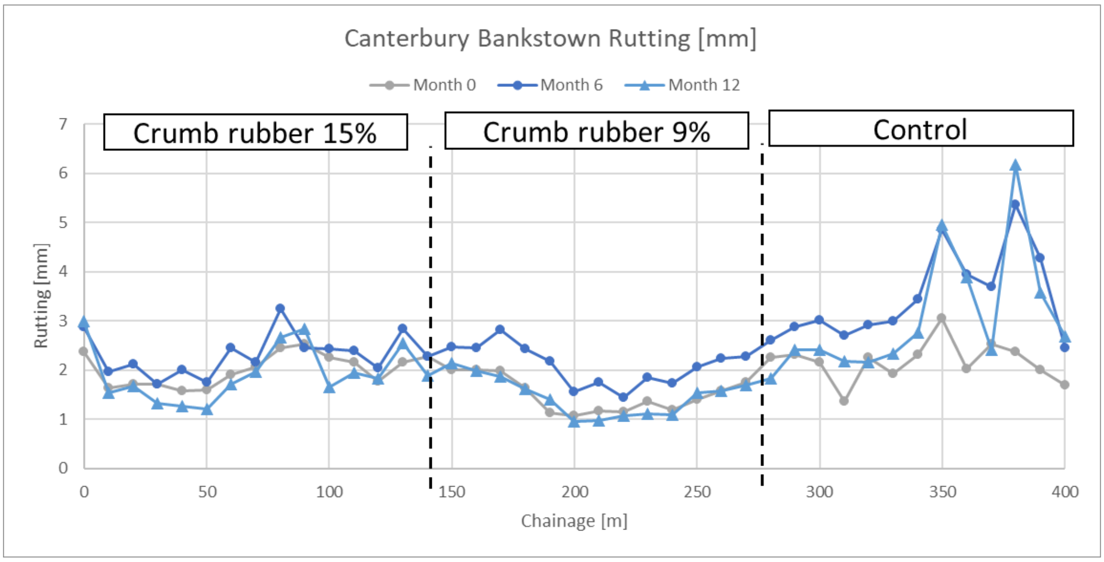


Figure 44 Evolution of rutting depth (mm) at City of Canterbury-Bankstown over 12 months

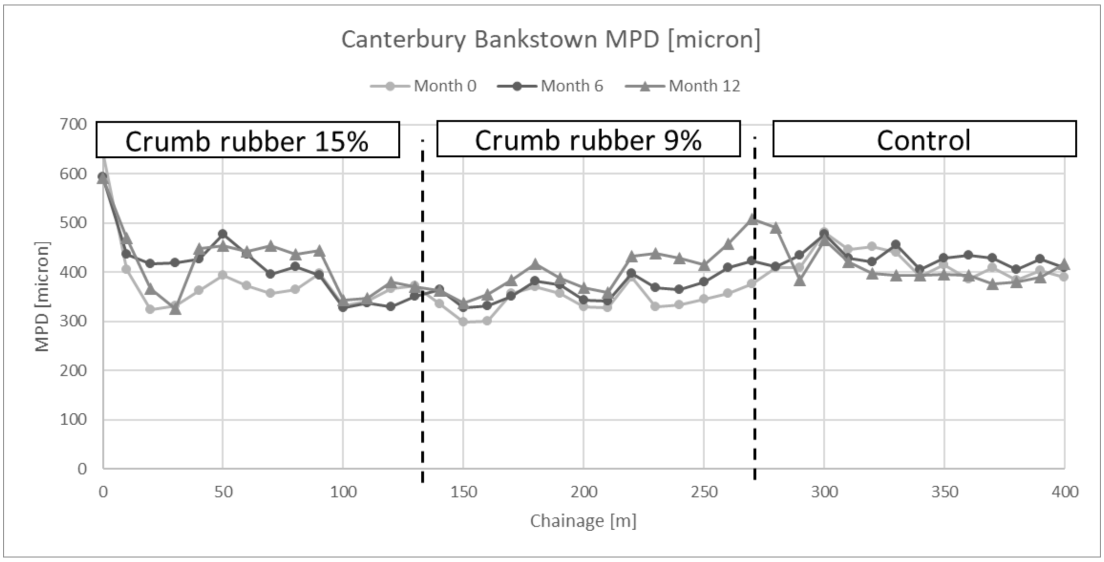


Figure 45 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at City of Canterbury-Bankstown over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since several pavement distresses can evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed for the evolution of IRI values over time. In general, average values of IRI between 1.7 m/km and 2 m/km are in the expected range for a road that has been resurfaced within 12 months. The CR 15% section presents an anomaly (i.e. a peak in the IRI graph) in the 12-month survey data possibly due to a localised distress.
- Both CRM asphalt sections show average rutting depth after 12 months below the value recorded for the control section. In general, approximately 45% reduction in rutting depth was observed over the first 12 months when CR is used in the asphalt mix. No major difference was observed between the mixes with 9% and 15% CR content.
- No major changes were observed in the macrotexture of the road. The use of CR (wet method) does not seem to affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.).

Refer to Table 11 and Figure 46 for a detailed analysis of the trends observed.

Table 11 Average values of IRI, rutting depth, and macrotexture at City of Canterbury-Bankstown

	Control	St.dev.	Crumb rubber 9%	St.dev.	Crumb rubber 15%	St.dev.
Average IRI [m/km]	2.0	0.8	1.7	0.4	1.9	1.4
Average Rutting depth [mm]	3.1	1.3	1.5	0.4	1.9	0.5
Average MPD [micron]	408	33.9	404	47.5	406	51.0

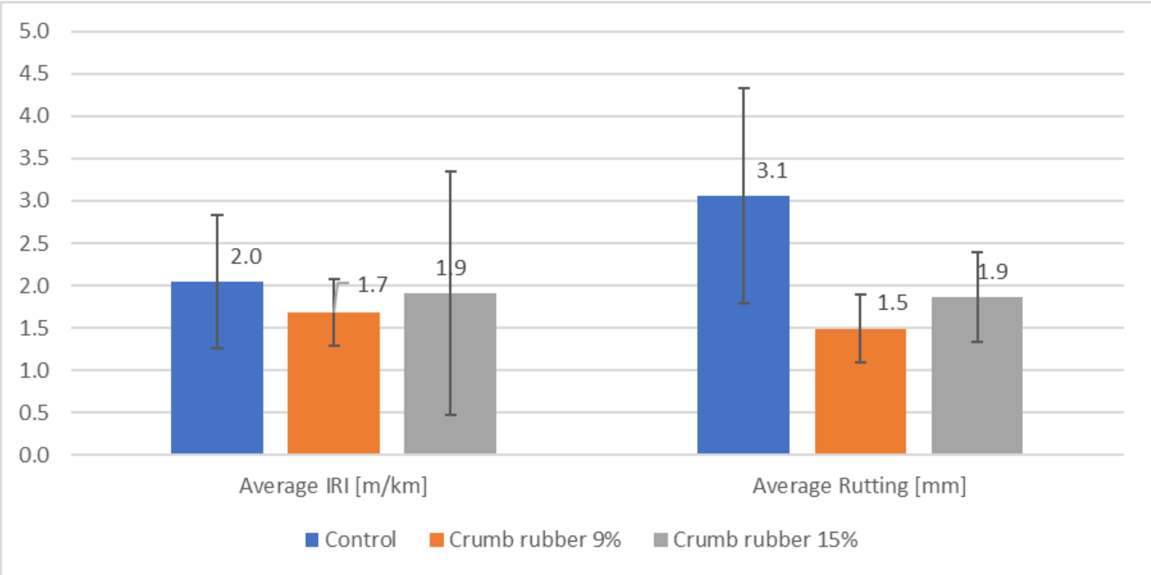


Figure 46 Average values of IRI, rutting depth, and macrotexture at City of Canterbury-Bankstown

4.11 Waverley Council, Yenda Avenue

4.11.1 Project Site description

Paving operations for Waverley Council were carried out on Yenda Avenue in October 2023 by State Asphalt NSW. Yenda Avenue is a narrow residential street located in the eastern suburbs of Sydney, New South Wales (Figure 47). It terminates in a cul-de-sac and primarily serves local residential traffic.

The road exhibited significant signs of deterioration, including longitudinal cracking, ravelling, and potholes. The scope of work involved a mill and fill resurfacing intervention using a single asphalt mix design. Due to the limited volume of asphalt required for this relatively short section of road, it was not feasible to include a second mix design (e.g., a control mix).

A dense-graded CRM) asphalt mix, produced via the wet method and containing approximately 15% rubber by weight of binder, was used for this project.

Figure 47 Project site at Waverley Council. The green hatched area shows the location of the crumb rubber modified asphalt. No control mix was laid at Waverley council due to the small size of the road project.

4.11.2 Materials and Mix design

The asphalt mix for the surface layer was identified by the contractor with the acronym AC10 S45R, indicating a dense graded mix, 10 mm nominal maximum aggregate size, S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder). 2.5% recycled crushed glass (as partial sand replacement) was also incorporated into this asphalt mix. No warm mix asphalt additive was used in this project. The bitumen (or binder) content was 6.8% for the CRM asphalt at 15% rubber.

4.11.3 Paving Operations

Paving operations were carried out by State Asphalt NSW over one day, the 6th of October 2023. The distance from the asphalt plant to the construction site was approximately 43.1 km. According to the paving records supplied by the contractor, just 63 tonnes of AC10 S45R asphalt (CRM asphalt) were laid. Overall, approximately 580 m^2 of Yenda Av. were paved using CRM asphalt.

The contractor did not report of any issues occurring during the paving operations, nor of any complaints due to asphalt fumes. The air voids content was measured on-site by the contractor using a Troxler Nuclear Density Gauge according to AS2891.14.2 and AS2891.14.5; the results show an average voids content of 3.4%.

4.11.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct post-construction monitoring at the project site. The International Roughness Index (IRI), rutting, and macrotexture were initially assessed in January 2024, approximately three months after completion of the works. However, the narrow width and geometry of the road made data collection with the survey vehicle challenging. The vehicle was forced to travel at a very low speed (approximately 10 km/h) with frequent trajectory adjustments. As a result, the data obtained during the first survey was deemed unreliable. Consequently, follow-up surveys at 6 and 12 months - conducted at other council sites - were not carried out for this location.

4.12 Georges River Council, O'Briens Rd.

4.12.1 Project Site description

Paving operations for Georges River Council were carried out on Woniora Road between King Georges Road and O'Brien's Road (Hurstville) in June 2023 by State Asphalt NSW. Woniora Rd. is a moderately trafficked (AADT 16,000 veh/day) road located in the southern suburbs of Sydney, New South Wales (Figure 48). The section of Woniora Road part of this demonstration project experienced significant construction traffic over the past few years due to recent developments in the area (mostly between O'Briens Rd. and Rosebank Cres. This has led to significant cracking and rutting along the wheel paths. In the past, heavy patching was conducted on the road as temporary remediation to the pavement distresses.

Three different asphalt mixes were used in this project, one for the asphalt base layer of the entire section of Woniora Rd. and two for the wearing course (one conventional and one modified with crumb rubber and other polymers). All asphalt mixes were dense graded. In particular, a dense-graded hybrid modified asphalt mix, produced via the wet method and containing approximately 15% rubber by weight of binder and SBS polymer, was used for this project. The intervention included milling of 150-200 mm of existing pavement, laying of 150 mm (control mix section) or 100 mm (crumb rubber section) asphalt base course, and 50 mm asphalt wearing course.

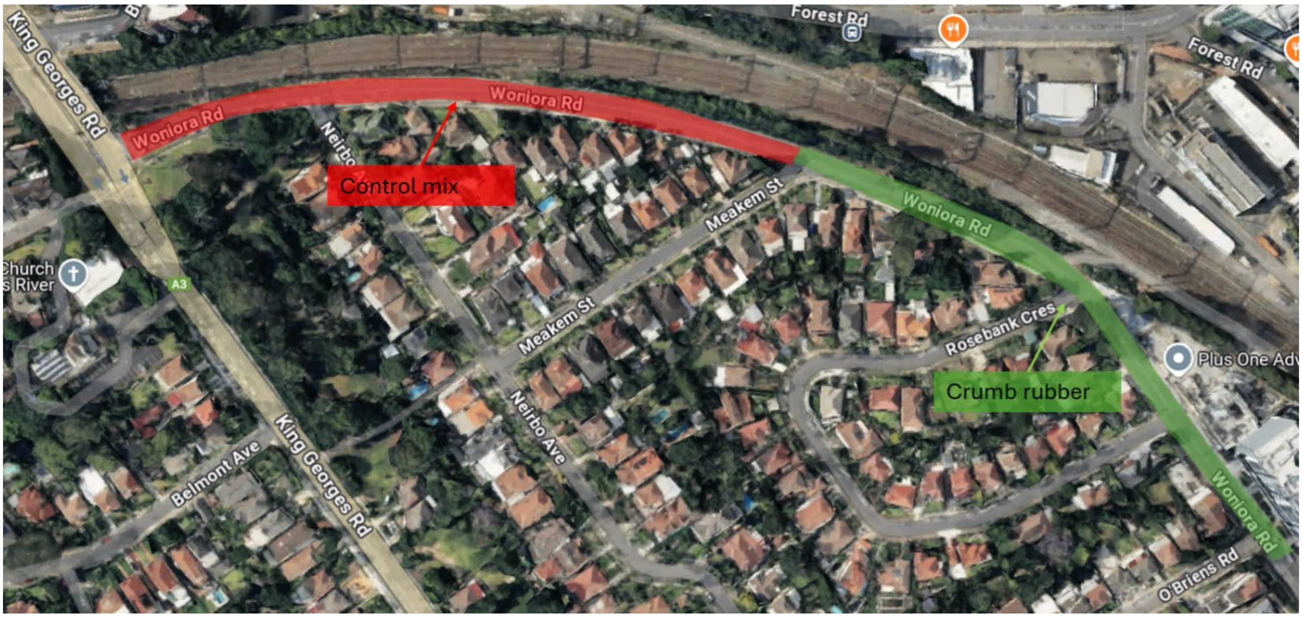


Figure 48 Project site at Georges River Council. The green hatched area shows the location of the crumb rubber modified asphalt, whereas the red hatched area shows the conventional asphalt mix design.

4.12.2 Materials and Mix design

The asphalt mixes for the surface layer were identified with the acronym AC14 C450 2.5%RCG 15%RAP and AC14 S45R SBS 2.5%RCG 15%RAP, indicating a dense graded mix, 14 mm nominal maximum aggregate size, C450 (conventional bitumen) or S45R binder (according to Austroads ATS3110 classification, approximately 15% of CR by weight of the binder). The content of SBS in the crumb rubber modified binder was not disclosed by the contractor. 2.5% recycled crushed glass (as partial sand replacement) was also incorporated into this asphalt mix with 15% RAP by weight of the total mix. No warm mix asphalt additive was used in this project. The bitumen (or binder) content was 6.2% for the hybrid SBS-CRM asphalt.

The asphalt base layer was identified as AC20 C450 10%RCG 30% RAP, indicating a dense graded mix, 20 mm nominal maximum aggregate size, C450 (conventional) bitumen, 10% recycled crushed glass, and 30% RAP by weight of the total mix. Note that 50 mm of the existing base course material in the crumb rubber section was retained as subbase to the new pavement (i.e. 50 mm existing base course, 100 mm new asphalt base layer, 50 mm SBS/CRM asphalt wearing course).

4.12.3 Paving Operations

Paving operations were carried out by State Asphalt NSW over two days, from the 27th to the 28th of June 2023. The distance from the asphalt plant to the construction site was approximately 25 km. According to the paving records supplied by the contractor, 344 tonnes of AC14 hybrid SBS/CRM asphalt were laid.

The contractor did not report of any issues occurring during the paving operations, nor of any complaints due to asphalt fumes. The on-site air voids content was not measured by the contractor, so the field void content is unknown.

4.12.4 Monitoring and Data Analysis

Infrastructure Management Group (IMG) was engaged by SSROC to conduct post-construction monitoring at the project site. Assessments of the International Roughness Index (IRI), rutting, and macrotexture were carried out in July 2023, January 2024, and July 2024.

The outcomes of the three monitoring runs are shown in Figure 49 to Figure 51. The traffic volume on Woniora Rd. prior to construction was approximately 16,000 veh/day (both directions) with approximately 3% heavy vehicles.

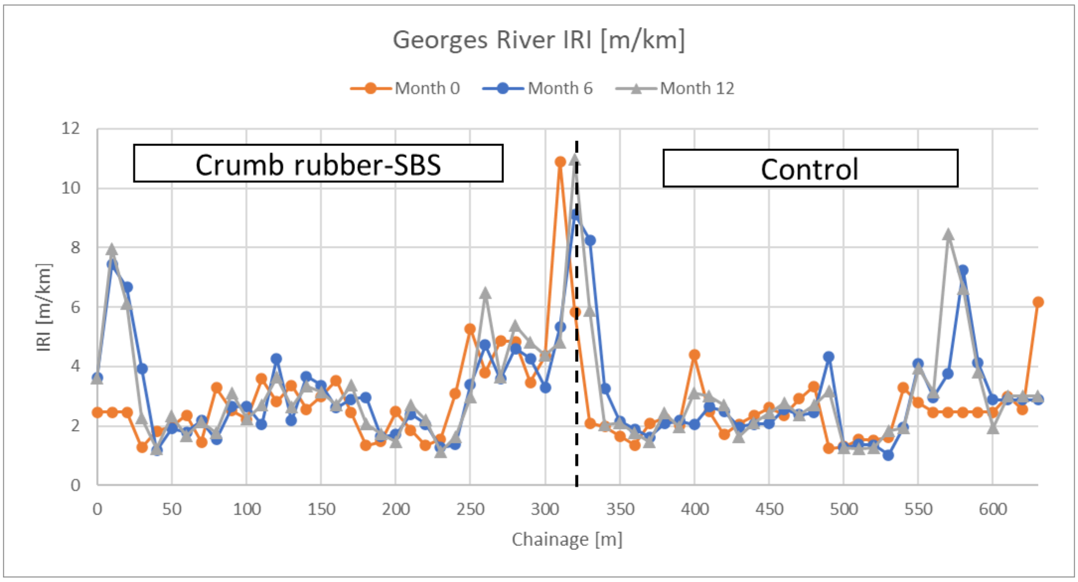


Figure 49 Evolution of the International Roughness Index (IRI, m/km) at Georges River Council over 12 months

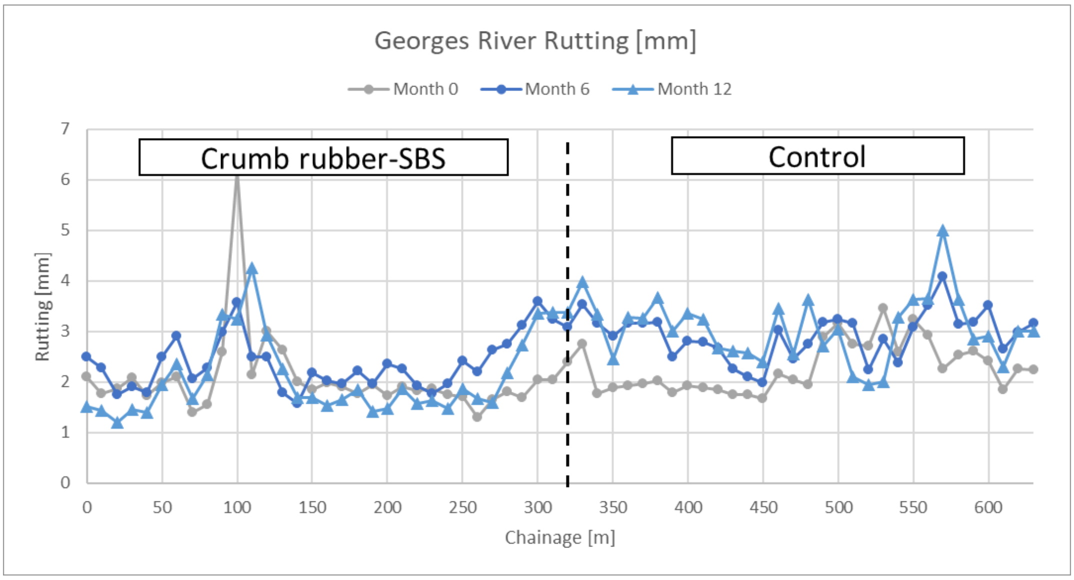


Figure 50 Evolution of rutting depth (mm) at Georges River Council over 12 months

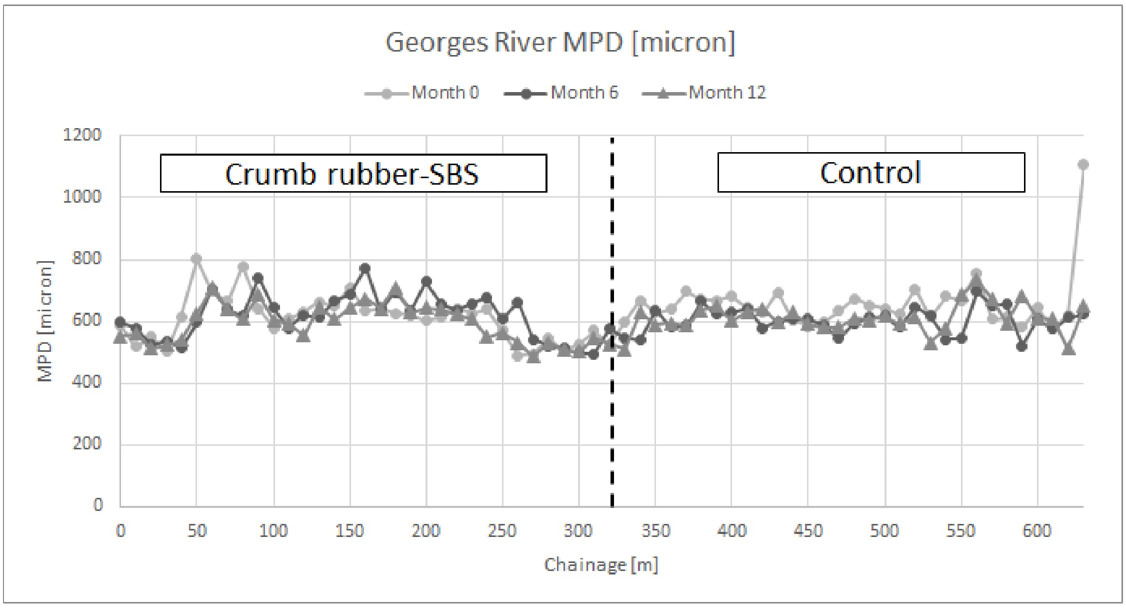


Figure 51 Evolution of macrotexture (Mean Profile Depth - MPD, micron) at Georges River Council over 12 months

SSROC and the councils that took part in this demonstration project are encouraged to continue monitoring the road conditions yearly since several pavement distresses can evolve with time, traffic, and environmental conditions. Therefore, what is captured by the previous graphs should only form a preliminary evaluation of the site conditions.

From the analysis of the 12-month data sets collected in the field, the following conclusions can be drawn.

- No clear trend can be observed for the evolution of IRI values over time. In general, average values of IRI between 2 m/km and 3 m/km are in the medium range for a road that has been resurfaced within 12 months. Note that the section of road leading to Meakem St. has considerably higher values of roughness compared to the rest of the road. Additionally, both sections present an anomaly (i.e. a peak in the IRI graph) in the 12-month survey data possibly due to a localised distress.
- The SBS/CRM asphalt section shows average rutting depth after 12 months below the value recorded for the control section. In general, approximately 32% reduction in rutting depth was observed over the first 12 months when the hybrid SBS/CR combination is used in the asphalt mix.
- No major changes were observed in the macrotexture of the road. The use of CR (wet method) does not seem to affect the functional properties of the road (i.e. friction during wet road conditions, safety, etc.).

Refer to Table 12 and Figure 52 for a detailed analysis of the trends observed.

Table 12 Average values of IRI, rutting depth, and macrotexture at Georges River Council

	Control	St.dev.	SBS/Crumb rubber 15%	St.dev.
Average IRI [m/km]	3.1	0.7	3.2	1.6
Average Rutting depth [mm]	3.1	0.6	2.1	0.8
Average MPD [micron]	608.2	44.7	593.1	61.9

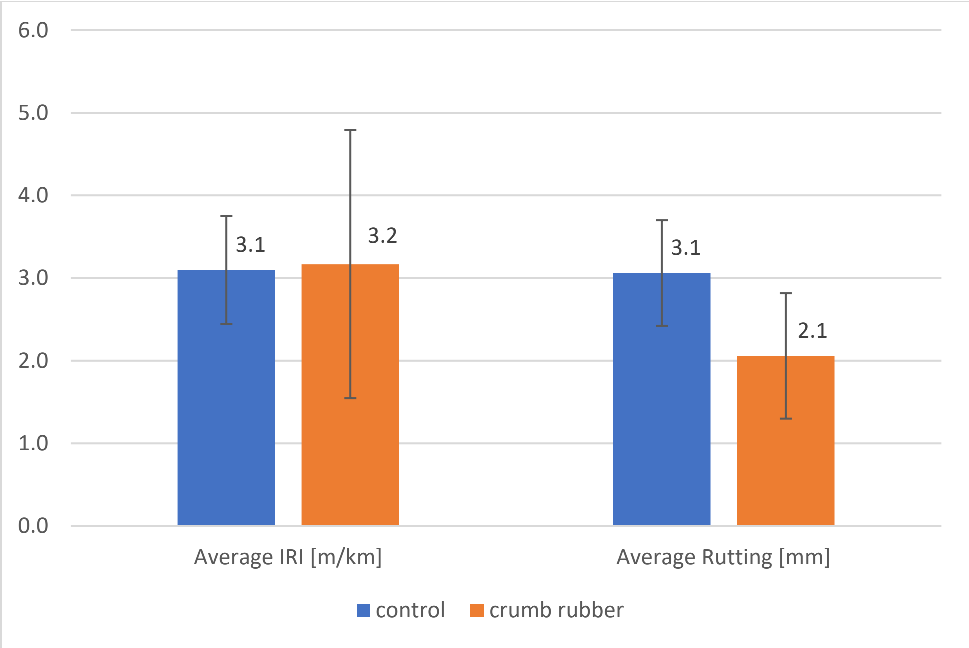


Figure 52 Average values of IRI, rutting depth, and macrotexture at Georges River Council

5 Conclusions

The SSROC demonstration project was a resounding success, showcasing the collaborative efforts of councils, industry associations, asphalt contractors, bitumen suppliers, and product stewardship organisations. This project - undeniably of national significance - stands as one of the few of its kind both in Australia and globally.

Twelve local governments collaborated to demonstrate the use of recycled materials in road construction through a data-driven, evidence-based approach. Specifically, the SSROC demonstration project highlighted the importance of recycling end-of-life vehicle tyres into crumb rubber for use in road applications via the wet method (i.e. bitumen modified with crumb rubber to produce a crumb rubber-modified binder).

Several asphalt mix designs were evaluated in the field, focussing on the feasibility of manufacturing and paving operations and assessing field performance. Variations in the thickness of pavement layers, the type of bitumen and crumb rubber-modified binder, the inclusion of warm mix additives, and the use of other recycled materials like recycled crushed glass and RAP were observed across the ten council projects. However, each project included a control section using conventional asphalt and at least one alternative section of crumb rubber-modified asphalt.

Based on the findings from this project and further discussions with stakeholders, the following conclusions can be drawn:

Industry Readiness:

- Road contractors encountered no issues when paving with crumb rubber-modified asphalt. Crumb rubber contents of 9% and 15% (by weight of the binder) were successfully incorporated into dense-graded asphalt wearing courses with nominal maximum aggregate sizes of 10 mm and 14 mm (i.e. AC10, AC14). Additionally, 18% crumb rubber (by weight of the binder) was effectively used in gap-graded asphalt mixes. The inclusion of recycled crushed glass and RAP did not present any challenges during manufacturing or paving operations. Most projects used warm mix asphalt additives to maintain lower manufacturing and paving temperatures, thereby minimizing potential fumes and reducing emissions associated with high-temperature production.
- Tyre recyclers showed that they can produce crumb rubber from passenger car tyres, truck tyres, or a combination of both. While specific tests on the properties of crumb rubber were not conducted by AfPA, contractors received certification of conformity from the tyre recyclers before commencing work.

Sustainability:

- Recycling end-of-life vehicle tyres into asphalt for road construction offers significant sustainability benefits. By repurposing waste tyres, which would otherwise contribute to landfill overflow or environmental pollution, the environmental impact associated with tyre disposal is reduced. The use of crumb rubber from tyres into asphalt enhances its performance and durability, leading to reduced maintenance needs and longer-lasting infrastructure. Previous research co-funded by SSROC highlighted that, when factoring in reduced maintenance interventions, there could be a reduction of up to 30% in the total environmental impacts over the service life of the infrastructure.
- The use of warm mix asphalt additives, alongside crumb rubber, offers dual environmental benefits: it reduces fumes and odours during manufacturing and paving, while also lowering energy consumption at the plant by requiring less energy to heat aggregates and bitumen. Note that none of the ten projects conducted under the SSROC demonstration project umbrella received any complaints regarding odours and fumes.
- The use of other recycled materials, such as recycled crushed glass and RAP, alongside crumb rubber, helps reduce environmental impacts by decreasing the need for natural resources, such as natural aggregates and bitumen.

Field Monitoring & Materials Evaluation:

- The air void content of crumb rubber-modified asphalt - measured in the field after construction - did not show any increase in pavement air voids or anomalies compared to conventional asphalt. This emphasises that while paving with crumb rubber may require more effort during construction (e.g. raking), the required road characteristics can still be achieved.
- The use of warm-mix additives does not affect road quality but helps limit fumes and odours during manufacturing and paving.
- The inclusion of additional recycled materials, such as crushed glass, does not appear to negatively impact road performance when crumb rubber-modified binder is used.
- Although no material testing was conducted by AfPA or SSROC, and considering that field performance after one year may not fully reflect long-term asset performance, the following findings can be summarised:
    - Rutting Resistance: 5 out of 10 projects showed improvements in rutting resistance ranging from 12% to 45%; four projects showed similar rutting depths after one year of monitoring, likely due to low traffic levels that resulted in minimal rutting; one project recorded greater rutting in the crumb rubber-modified section compared to the conventional asphalt section (however, the conventional asphalt section included RAP); and one project had no field monitoring data. Overall, the data suggests that crumb rubber-modified asphalt performs equal to or better than conventional asphalt in 80% of cases.
    - Roughness: Continuous measurement of roughness (e.g. IRI) on local roads is made complicated by traffic, road size, and external factors like the presence of traffic lights, pedestrian crossings, and utility services. Findings from roughness monitoring do not show a clear trend in its evolution over time. For example, roughness after 12 months was not consistently worse than after 1 or 6 months, suggesting inconsistencies in the road survey measurements, likely due to the factors mentioned above. Overall, 5 out of 11 projects showed similar IRI values between conventional asphalt and crumb rubber-modified asphalt; 4 out of 11 projects showed similar IRI values, but the crumb rubber-modified asphalt section had a lower IRI (i.e. improvement) on average; 1 out of 11 projects had similar IRI values, but the conventional asphalt section had a lower IRI (i.e. improvement) on average; and 1 out of 11 projects had no field monitoring data. Overall, the data suggests that the roughness of crumb rubber-modified asphalt roads is equal to or better than conventional asphalt roads in approximately 80% of cases.
    - Macrotexture: In general, road's macrotexture, which affects friction in wet conditions, is primarily determined by aggregate gradation and, to a lesser extent, bitumen content. Field monitoring results indicate that using crumb rubber-modified bitumen does not significantly affect macrotexture, whether positively or negatively. Furthermore, variations in macrotexture were mainly observed between sections with different aggregate gradations (i.e. gap-graded asphalt vs. dense-graded asphalt).
- No significant difference was observed in asphalt performance over the short term (i.e. 1 year) based on the source of the crumb rubber (i.e. truck tyres, passenger car tyres, or a combination of both).
- A 9% crumb rubber content appears to be as effective as 15% crumb rubber in the short term (i.e. 1 year). Further testing and field observations are needed to confirm this trend over time.
- The use of dense-graded asphalt with 9% or 15% crumb rubber (by weight of the binder) appears to be suitable for most local government applications. Due to its higher cost, gap-graded asphalt with 18% crumb rubber (by weight of the binder) should be considered only for high-traffic areas (i.e. more than 15,000 vpd) and where high levels of wet friction (macrotexture) are required.

Overall, the SSROC project demonstrated that crumb rubber-modified asphalt (wet method) is an effective way to improve recycling practices and enhance the sustainability of road infrastructure, while also improving the quality and performance of local roads.