University of Nottingham
Nottingham Transportation Engineering Centre

Asphalt Preservation & Rejuvenation

CEDR Live Labs 2 South Campus

Phase 2 Final Report

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Executive Summary

This report presents the findings of a laboratory evaluation conducted by TARMAC, under the CEDR Live Labs 2 South Campus initiative. The primary objective of this Phase 2 study was to investigate the effectiveness of proprietary asphalt preservation and rejuvenation treatments, specifically PenTack and Reclamite, in extending the service life of aged pavements. Testing was performed on core samples extracted from multiple highway locations across a wide span of pavement service ages (ranging in age from 1 to over 17 years) and consisting of two asphalt mixture designs: Hot Rolled Asphalt (HRA) and Stone Mastic Asphalt (SMA). The laboratory programme comprehensively analysed mixture volumetrics (air voids), binder content, indirect tensile stiffness, and hydraulic conductivity alongside the basic and rheological properties of the recovered binders (penetration, softening point, and Dynamic Shear Rheometer frequency sweep measurements). The experimental findings demonstrated that both PenTack and Reclamite treatments softened the aged binder effectively. Key outcomes include (1) preservation of core structural stability, with moderate enhancements in Indirect Tensile Stiffness Modulus (ITSM) values, (2) a profound drop in water infiltration across highly permeable, older pavement sections (e.g., reductions of up to 88% on old HRA surfaces), (3) successful rejuvenation of severely aged binders, highlighted by measurable increases in penetration, reductions in softening point temperatures, and a beneficial reclassification of binder rheology from highly stiff categories (Category C) into flexible operating brackets (Category B or A-B). The evidence gathered during this phase 2 programme confirms that these surface-applied rejuvenators offer effective proactive maintenance strategies to mitigate binder oxidation and prevent water ingress.

1 Introduction

Over time, asphalt pavements undergo severe environmental weathering and binder oxidation, leading to bitumen embrittlement, micro-cracking, and ravelling. To address these issues, proactive bitumen preservation treatments have emerged as a viable option to treat early-stage deterioration before critical structural failure occurs. This study, conducted as part of the CEDR Live Labs 2 South Campus phase 2 framework, systematically evaluates the performance of two commercial rejuvenators (PenTack and Reclamite) applied to in-service (1 to 17+ years old) roads. The core samples analysed in this research were retrieved from the site locations include Jimmy Hill Way, Auckland Drive, A41 The Expressway, A452 Collector Road, A4123 Wolverhampton Rd, Longwood Lane, and Aldridge Road. The asphalt mixture types and rejuvenators utilised across these road sections are detailed in Section 2 (Materials). Furthermore, the laboratory performance tests conducted on the asphalt mixtures and extracted binders are outlined in Sections 3 and 4.

2 Materials

This study evaluated the behaviour of rejuvenators through core samples retrieved from various in-service roads as listed in Tables 1 and 2. The existing roads consist of two different asphalt mixture types: Hot Rolled Asphalt (HRA) and Stone Mastic Asphalt (SMA). The age of the pavements at the time of sampling ranges from relatively new overlays (1 year) to sections exceeding 17 years in service. To assess the efficacy of asphalt preservation treatments, the material properties of sections treated with proprietary rejuvenators specifically PenTack and Reclamite were directly compared against with their corresponding untreated Control sections. The locations with HRA and SMA mix designs, along with the ages of the existing pavements, are detailed below:

1. **HRA Sites:** Includes locations such as Jimmy Hill Way S2 (17+ years), Auckland Drive (9 years), and A41 The Expressway (13 years).
2. **SMA Sites:** Includes Jimmy Hill Way S1 (7 years), A452 Collector Road (9 years), A41 The Expressway (1 year and 13 years), A4123 Wolverhampton Rd (5 years), Longwood Lane (6 years), and Aldridge Road (10 years).

A summary of the core volumetric properties, including binder content (ranging from 5.2% to 7.2% by mass) and air voids content (ranging from 0.2% to 7.0%), is shown in Table 1 and Table 2.

3 Laboratory Testing Programme

The laboratory testing programme was designed to evaluate the performance of the treated and untreated asphalt mixtures, as well as their extracted binders, through the following procedures:

- The air voids content of the cored specimens was measured in accordance with BS EN 12697-6:2020.
- The cored specimens were tested for indirect tensile stiffness modulus (ITSM) in accordance with BS EN 12697-26:2004.
- In addition, hydraulic conductivity testing was performed to understand the permeability of asphalt mixtures after surface treatments.
- The asphalt binder was extracted and recovered from the asphalt cores received from the different roads.
- The efficiency of rejuvenators was then evaluated through the viscoelastic properties (G^* and δ) of the recovered binders.

Table 1: Locations with HRA mix type

Location	Product	Asphalt Type	Age since last resurfaced	Lab Sample ID	T(VET) (degree) - DSR	G*(VET) (MPa)-DSR	Table E/2.1 1 of CD227 Category	Penetration (0.1mm)	Softening Point (degree)	ITSM Mean Stiffness (MPa)	Air Voids (%)	Binder Content (mass %)	DSR Raw Data?	Relative hydraulic conductivity (mm/hr) ID 1	Relative hydraulic conductivity (mm/hr) ID 2	Relative hydraulic conductivity (mm/hr) ID 3	Avg hydraulic conductivity (mm/hr)
Jimmy Hill Way S2	Control	HRA	17+ years	26.0125	15.2	6.06	A-B	25	58.2	2502	0.2	7.2	Y	385	792	610	595.7
	PenTack	HRA	17+ years	26.0126	16.2	5.47	A-B	26	58.6	2569	1.2	6.3	Y	63	70	N/A	66.5
Auckland Drive	Control PenTack	HRA	9	26.0148	5.6	17.12	A	56	43.8	1898	3.7	5.5	Y	0	0	0	0.0
	PenTack	HRA	9	26.0149	6.6	16.57	A	53	44.6	2393	7	5.6	Y	0	0	0	0.0
	Control Reclamite	HRA	9	26.0150	1.7	27.95	A	83	40.4	1513	1.8	5.3	Y	0	0	0	0.0
	Reclamite	HRA	9	26.0151	4.6	18.24	A	66	42.2	2131	1.5	5.7	Y	0	0	0	0.0
A41 The Expressway	Control	HRA	13	26.0172	22.6	0.84	C	35	74.8	833	1.3	5.9	Y	1008	1762	1144	1304.7
	PenTack	HRA	13	26.0173	16.5	1.75	A-B	40	73.6	1197	0.7	6.1	Y	234	175	167	192.0

Table 2: Locations with SMA mix type

Location	Product	Asphalt Type	Age since last resurfaced	Lab Sample ID	T(VET) (degree) - DSR	G*(VET) (MPa)-DSR	Table E/2.11 of CD227 Category	Penetration (0.1mm)	Softening Point (degree)	ITSM Mean Stiffness (MPa)	Air Voids (%)	Binder Content (mass %)	DSR Raw Data?	Relative hydraulic conductivity (mm/hr) ID 1	Relative hydraulic conductivity (mm/hr) ID 2	Relative hydraulic conductivity (mm/hr) ID 3	Avg hydraulic conductivity (mm/hr)
Jimmy Hill Way S1	Control	SMA	7	26.0123	18.1	7.44	B	19	58	2738	4.8	6.3	Y	38	155	114	102.33
	PenTack	SMA	7	26.0124	19.7	6.64	B	18	59.6	2710	5.5	6.3	Y	40	43	N/A	41.50
A452 Collector Road	Control PenTack	SMA	9	26.0152	25.4	5.12	C	12	63.6	2824	6.1	5.3	Y	367	294	339	333.33
	PenTack	SMA	9	26.0153	20.4	5.9	B	19	53.6	3212	4.3	5.2	Y	0	0	0	0
	Control Reclmite	SMA	9	26.0154	20.7	5.69	C	18	59.2	2937	3.7	5.4	Y	367	304	339	336.66
	Reclamite	SMA	9	26.0155	17.5	6.32	B	24	54.8	2977	1.6	5.6	Y	37	38	37	37.33
A41 the express way	Control	SMA	13	26.0146	25.8	8.26	C	10	69	2312	6.7	6.1	Y	203	174	169	182.00
	PenTack	SMA	13	26.0147	19.9	6.95	B	15	62.4	3100	4.9	6.3	Y	28	26	25	26.33
	Control	SMA	1	26.0174	17.5	7.83	B	21	53.4	2987	4.2	5.7	Y	0	0	0	0
	PenTack	SMA	1	26.0175	14.6	8.88	A-B	26	50.6	3417	2.9	5.6	Y	0	0	0	0
A4123 Wolverhampton Rd	Control	SMA	5	26.0176	18.9	5.32	B	25	53.2	3821	0.8	5.9	Y	0	0	0	0
	PenTack	SMA	5	26.0177	17.9	6.2	B	26	54	3372	0.6	7.1	Y	0	0	0	0
Longwood Lane	Control	SMA	6	26.0163	15.5	8.84	A-B	21	54.2	2790	4.9	6.1	Y	0	0	0	0
	PenTack	SMA	6	26.0164	15.5	10.46	A	24	53.4	3225	3.4	6.2	Y	0	0	0	0
Aldridge Road	Control	SMA	10	26.0161	25.3	5.67	C	12	64.4	2303	6.3	6.5	Y	114	110	112	112.00
	PenTack	SMA	10	26.0162	23.1	5.89	C	15	62.4	1785	6.4	6	Y	0	0	0	0

4 Test Results, Analysis and Discussion

4.1 Air Voids and Binder Content

Figure 1 and Figure 2 shows the air voids content of the SMA and HRA cores. The air voids content of the SMA cores showed notable variation across different locations, ranging from a very low 0.6% at the cored section of A4123 Wolverhampton Rd (PenTack) up to 6.7% at the untreated Control section of A41 The Expressway (Figure 1). Generally, treated sections (either Reclamite or PenTack) exhibited lower air voids compared to their respective controls, suggesting that the surface treatments penetrated the void structure or provided a sealing effect. For HRA cores, air voids were mostly low compared to SMA (Figure 2). Across all sites, binder content remained relatively stable between the control and treated sections, indicating that the surface applications did not significantly alter the bulk binder mass metrics. SMA binder content ranged from 5.2% to 7.1%, while HRA binder content ranged from 5.3% to 7.2% (Figure 3 and Figure 4).

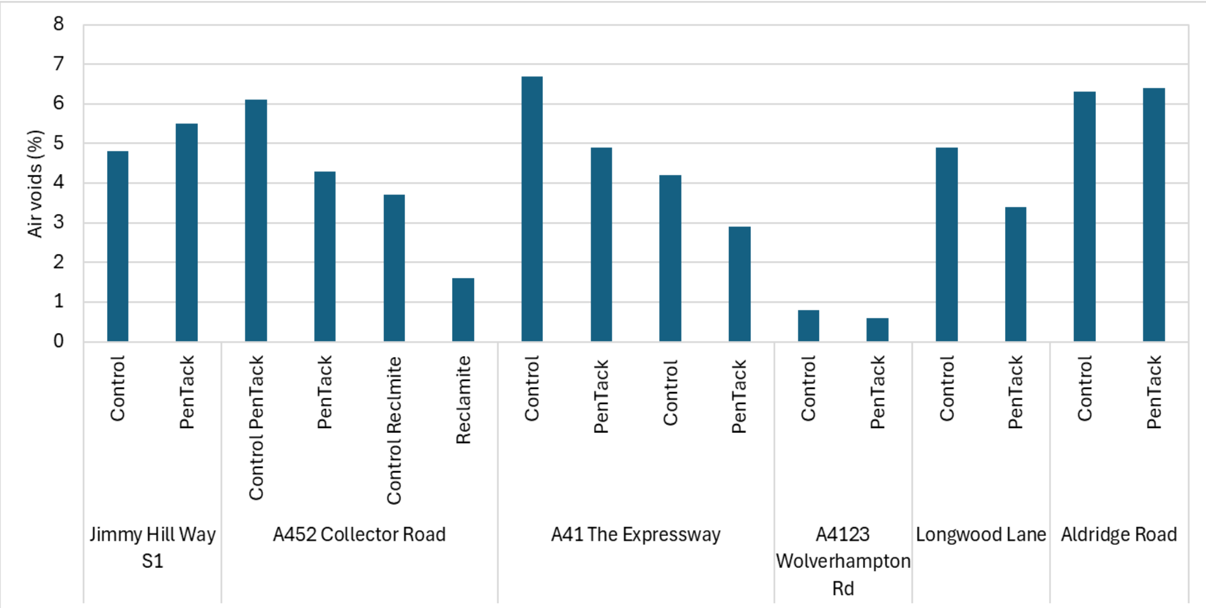

Figure 1. Air voids of SMA cores

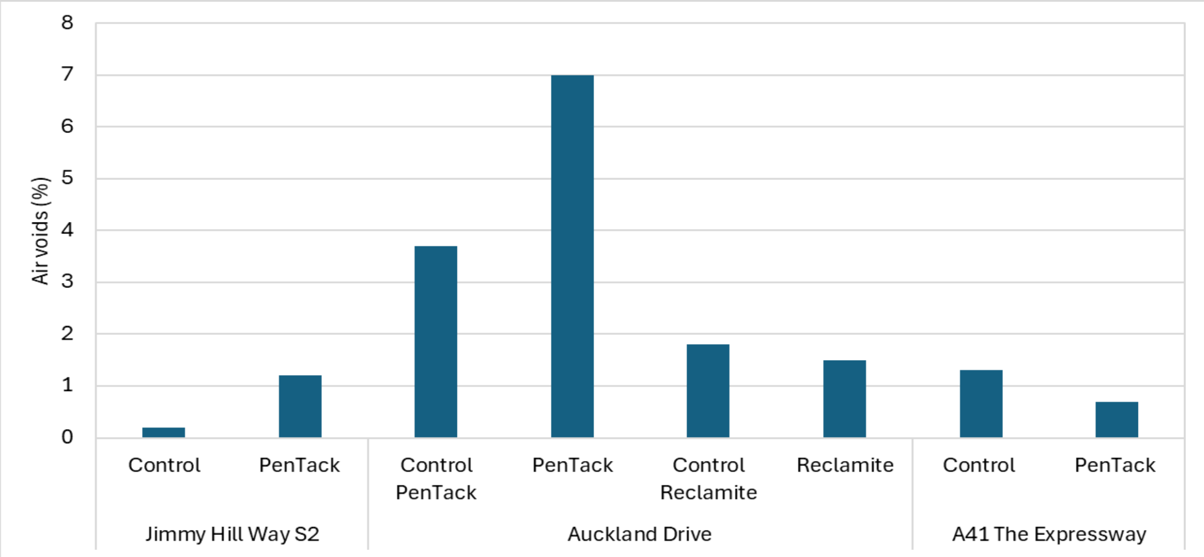

Figure 2. Air voids of HRA cores

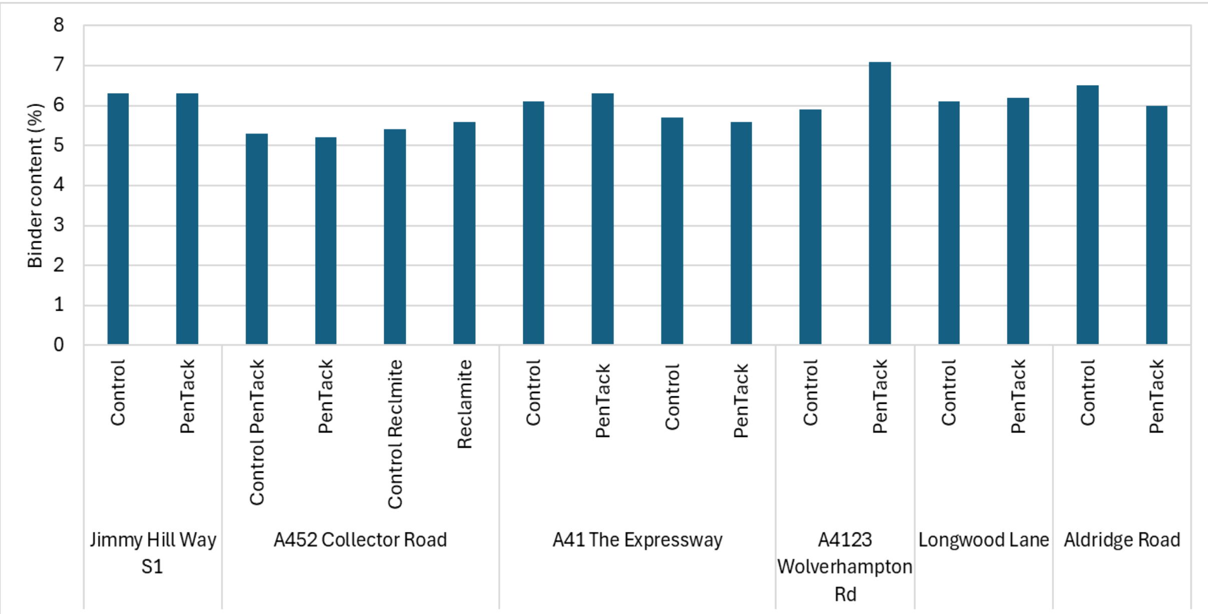

Figure 3. Binder content of SMA cores

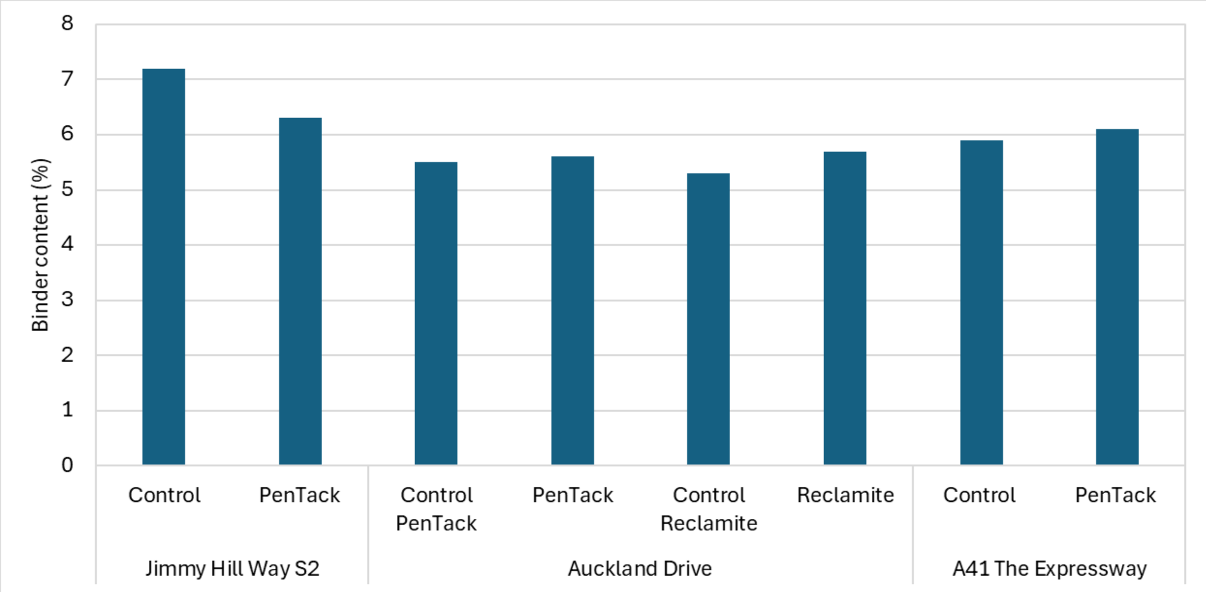

Figure 4. Binder content of HRA cores

4.2 Indirect Tensile Stiffness Modulus (ITSM)

Figure 5 and Figure 6 shows the ITSM values of SMA and HRA cores. The ITSM for SMA cores varied from 1,785 MPa (Aldridge Road, PenTack) to 3,821 MPa (A4123 Wolverhampton Rd, Control) (Figure 5). In many of the SMA locations, such as the A452 Collector Road, A41 The Expressway (both the 1-year and 13-year sections), and Longwood Lane, the sections treated with PenTack or Reclamite demonstrated an increase in core stiffness compared to their untreated control samples. The HRA sections exhibited lower stiffness values than the SMA sections (Figure 6). In the HRA cores, similar to the SMA results, surface treatments generally led to a moderate increase in the overall mixture stiffness; for example, on the A41 Expressway, the control stiffness of 833 MPa increased to 1,197 MPa with the PenTack treatment.

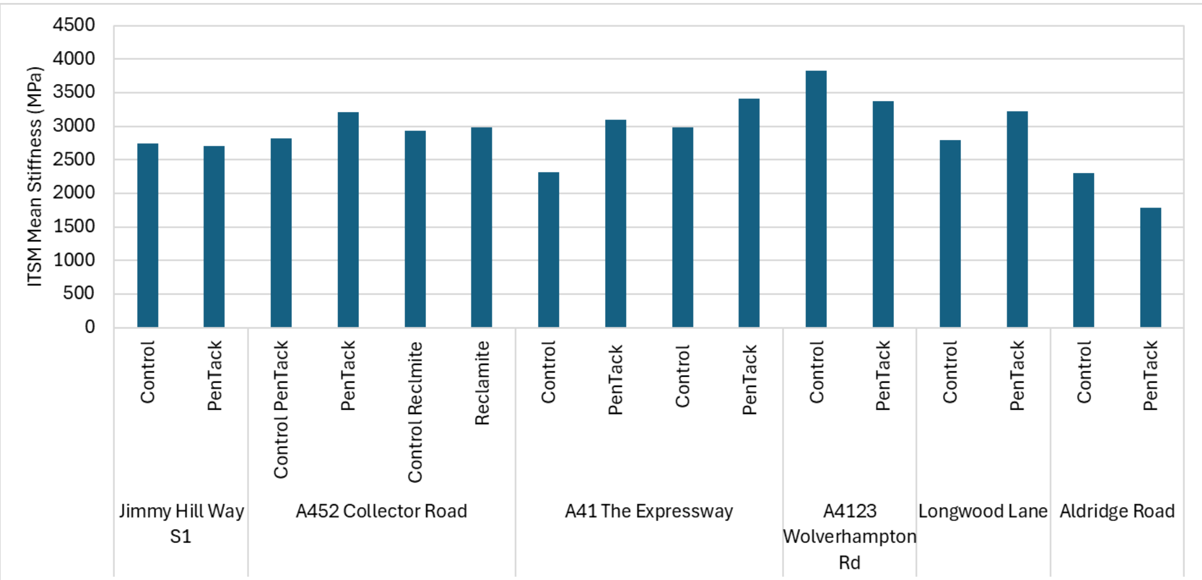

Figure 5. Stiffness of SMA cores

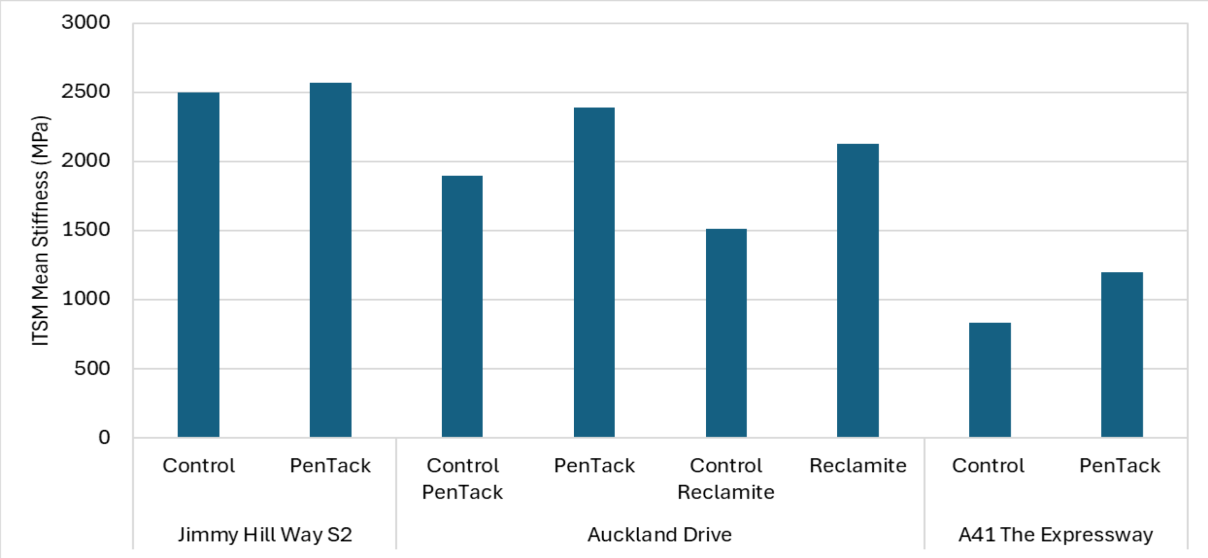

Figure 6. Stiffness of HRA cores

4.3 Water Permeability

Hydraulic conductivity values indicated that a few cores in highly dense SMA sections (such as A4123 Wolverhampton Rd and Longwood Lane) were completely impermeable, with a relative hydraulic conductivity of 0 mm/hr for both control and treated cores (Figure 7 and Table 2). For permeable SMA sections, the application of rejuvenators significantly reduced water infiltration. On the A452 Collector Road, the control relative hydraulic conductivity dropped sharply from over 333 mm/hr down to 0 mm/hr (PenTack) and 37.33 mm/hr (Reclamite). A similar reduction was observed at Jimmy Hill Way S1 and A41 The Expressway.

Auckland Drive HRA cores were entirely impermeable (0 mm/hr) across all variations (Figure 8 and Table 1). However, on highly permeable, older pavements, the sealing/penetration efficacy of the rejuvenators was high: at Jimmy Hill Way S2 (17+ years old), conductivity dropped from 595.7 mm/hr (Control) to 66.5 mm/hr (PenTack). On the 13-year-old HRA section of A41 The Expressway, the average conductivity decreased from a severe 1,304.7 mm/hr down to 192.0 mm/hr following PenTack application.

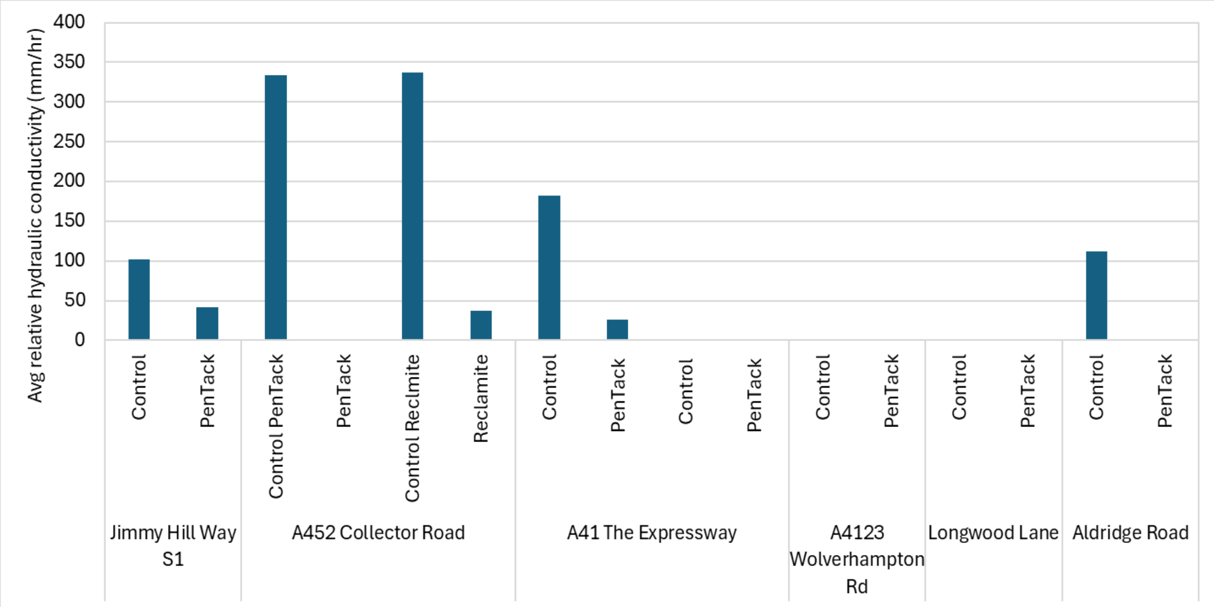

Figure 7. Hydraulic conductivity of SMA cores

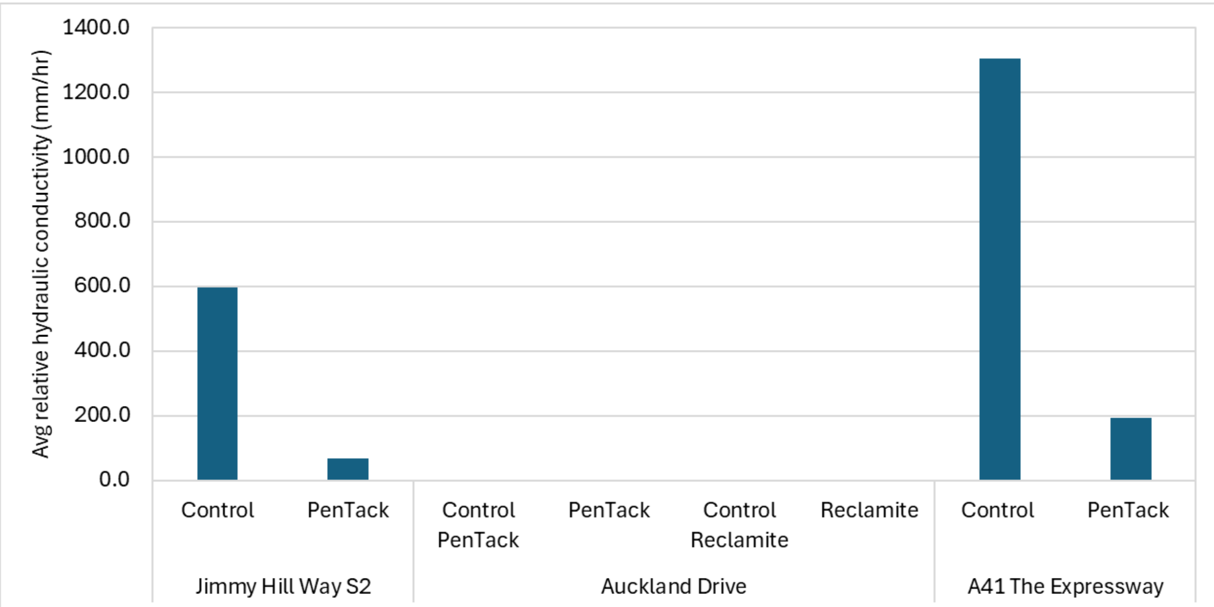

Figure 8. Hydraulic conductivity of HRA cores

4.4 Basic Properties of Recovered Binders

The binders were extracted and recovered from the full surface layer of the cores, and the penetration and softening point data revealed that the treatments successfully softened the aged binders in various sections (Figure 9, Figure 10, Figure 11, Figure 12). For instance, on the 9-year-old HRA site at Auckland Drive, the Reclamite treatment increased the binder penetration value from 56 dmm (Control) to 66 dmm. Similarly, in the SMA section of the A452 Collector Road (9-year-old), the Reclamite treatment increased binder penetration value from 18 dmm (Control) to 24 dmm.

Reflecting the penetration improvements, treatments often lowered the softening point of the extracted binders, indicating reduced brittleness. On the A452 Collector Road (SMA, 9-year-old), PenTack dropped the softening point from 63.6°C to 53.6°C, and Reclamite dropped it from 59.2°C to 54.8°C. On the 1-year-old SMA section of A41 The Expressway, PenTack reduced the softening point from 53.4°C to 50.6°C.

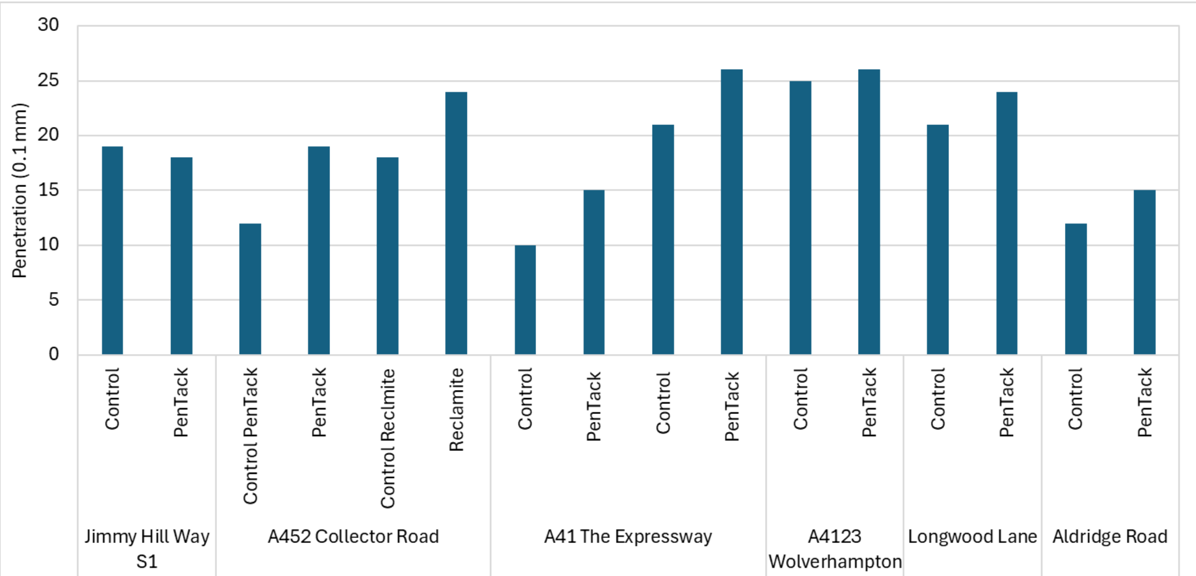

Figure 9. Penetration of binders extracted from SMA sections

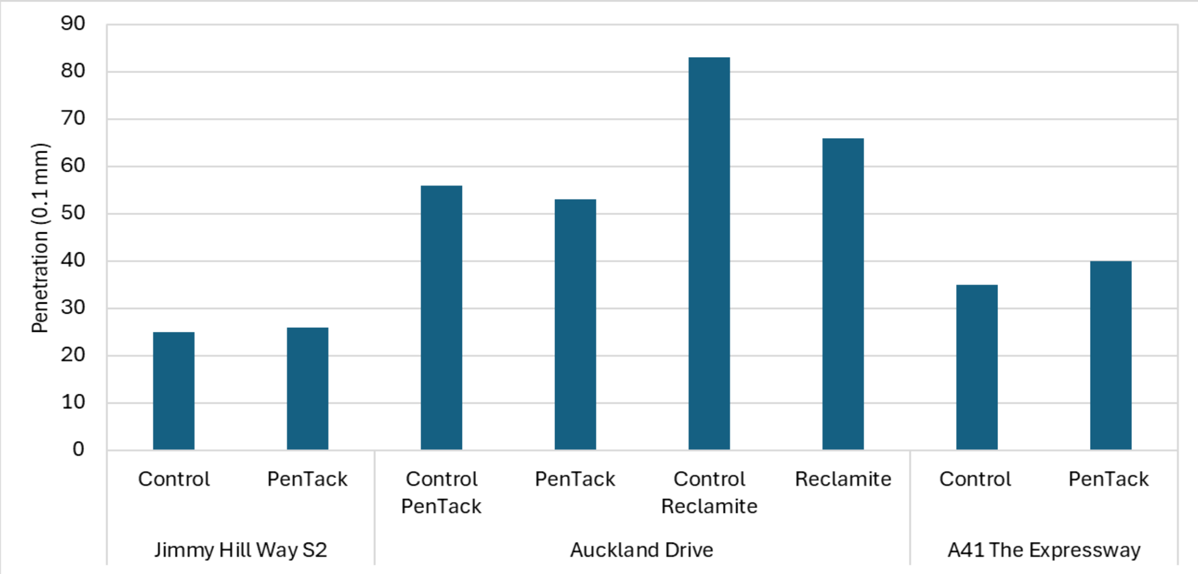

Figure 10. Penetration of binders extracted from HRA sections

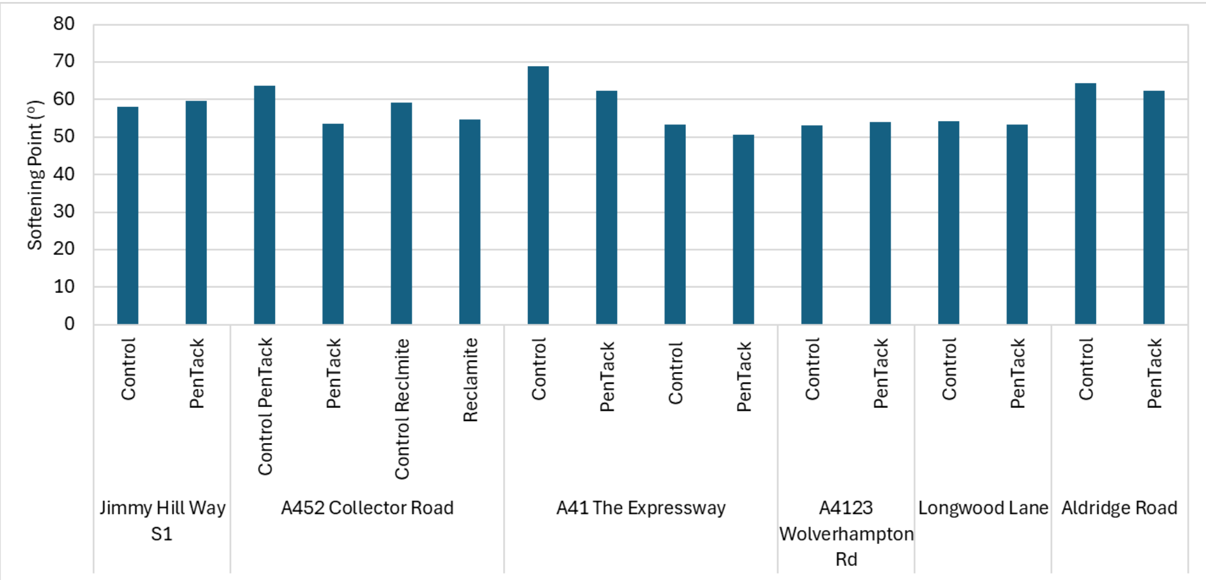

Figure 11. Softening point of binders extracted from SMA sections

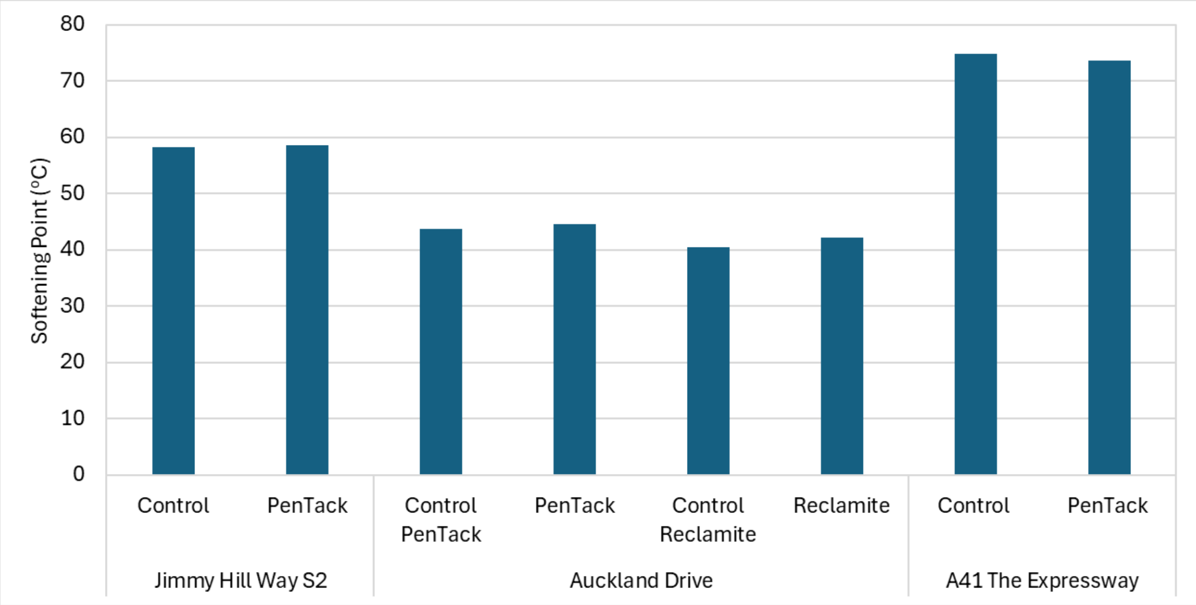

Figure 12. Softening point of binders extracted from HRA sections

4.5 Stiffness of Recovered Binders

Figure 13 to Figure 17 present the complex moduli of the binders extracted from the SMA and HRA cores. In phase 2, while the surface treatments increased the ITSM stiffness values of asphalt mixtures, they reduced complex moduli values of the recovered binders. It is important to note that the binders were extracted from the full depth of the surface layer rather than being sectioned into three portions (top, middle and bottom), as was done in the NTEC phase 1 study. Therefore, the penetration depth efficiency of the rejuvenators is not discussed in this report. The bulk binder results indicate that the surface treatments moderately reduced the complex moduli compared to their corresponding untreated control binders.

The rheological performance of the binders was classified based on the equi-viscous temperature (T_{VET}) and complex shear modulus (G^*_{VET}) at which the phase angle (δ) reaches 45° under Dynamic Shear Rheometer (DSR) testing at a frequency of 0.4 Hz. Identifying the sol-gel transition point, where the material behaviour shifts from viscous to elastic, allows the classification of the surface treatments as detailed in Table 3.

Table 4 and Table 5 presents the categories of binders recovered from HRA and SMA sections.

Both the PenTack and Reclamite treatments demonstrated a clear capability to alter the rheological profile of the binder, shifting highly aged binders out of critical brackets. For example, multiple untreated control binders classified under Category C (highly aged/stiff, such as the SMA sections on A452 Collector Road, Aldridge Road, and the 13-year-old A41 Expressway) successfully transitioned to a more flexible Category B or A-B classification after rejuvenator application.

In A452 Collector Road SMA cores, the heavily oxidized baseline control binders for both PenTack and Reclamite sections originally classified as Category C, which represents highly aged, brittle properties. Following treatment, both PenTack and Reclamite successfully transitioned the binders into the flexible Category B range. Reclamite reduced the T_{VET} from 20.7°C down to 17.5°C. PenTack lowered its corresponding T_{VET} from 25.4°C down to 20.4°C. Although both treatments significantly softened the binder with PenTack reducing the T_{VET} by 5°C and Reclamite by 3.2°C, this rheological behaviour should be further substantiated with chemical evidence.

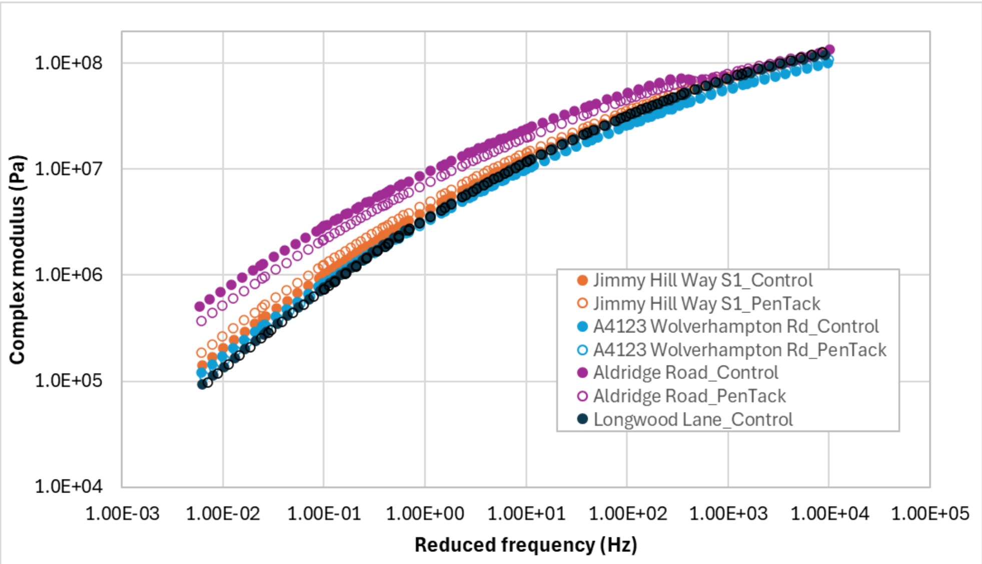

Figure 13. Complex modulus of SMA sections- Part 1

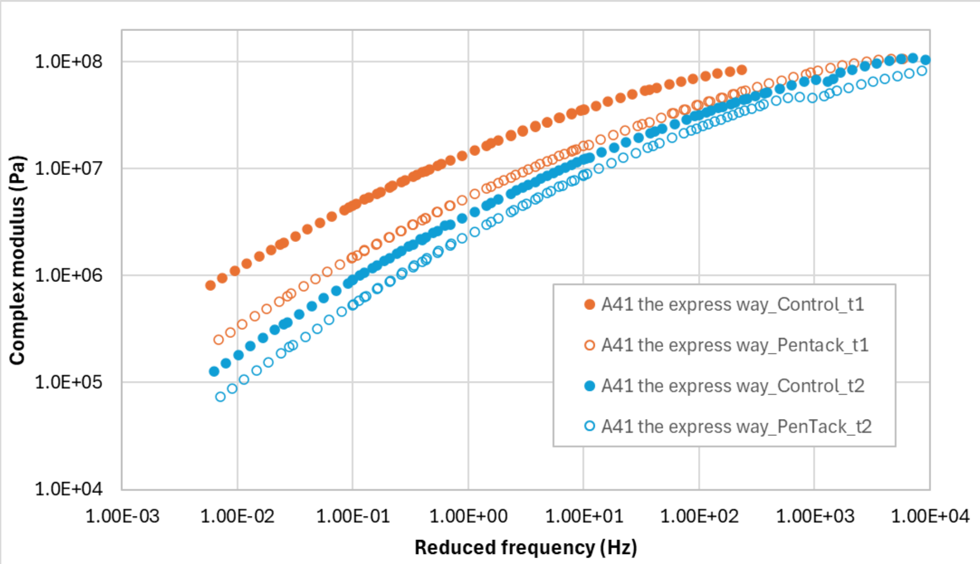

Figure 14. Complex modulus of SMA sections- Part 2

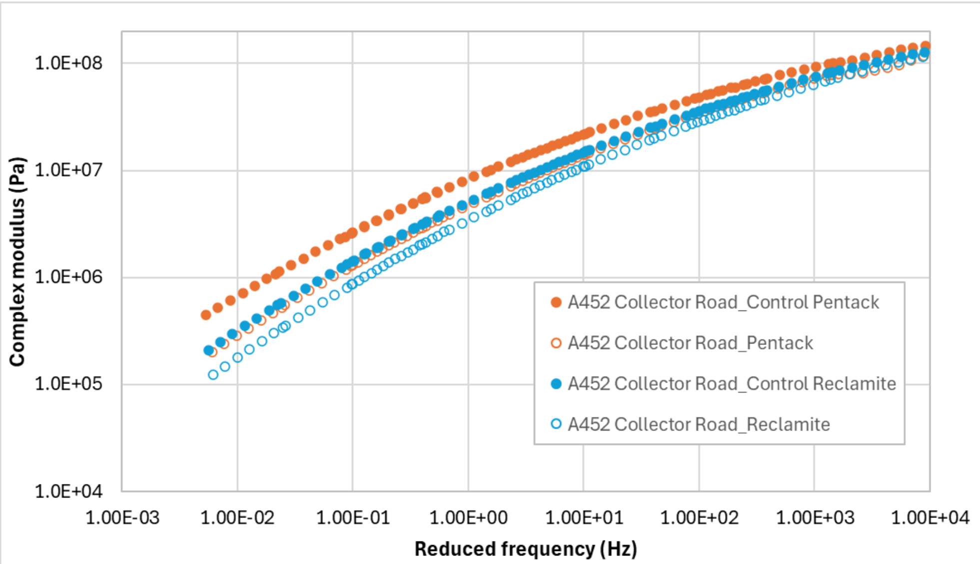

Figure 15. Complex modulus of SMA sections- Part 3

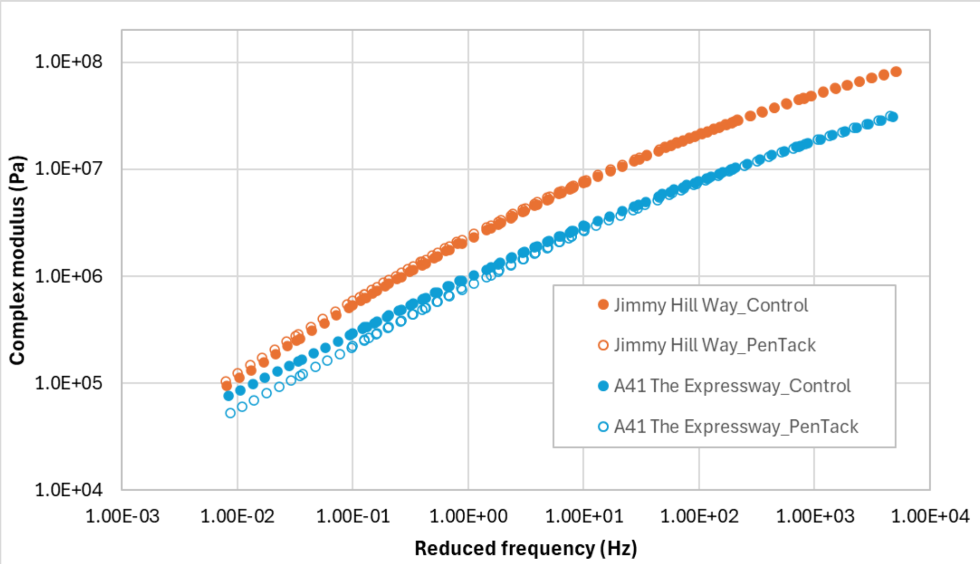

Figure 16. Complex modulus of HRA sections- Part 1

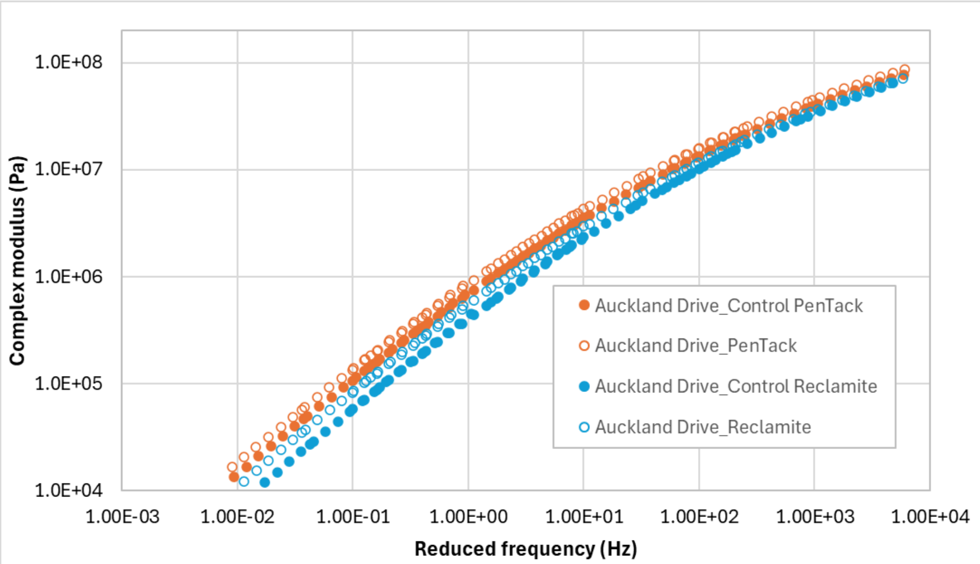

Figure 17. Complex modulus of HRA sections- Part 2

Table 3.Categories to analyse the suitability of surface treatment

Category	$T_{(VET)}$ °C	$G^*_{(VET)}$ MPa	Condition	Recommendation
A	< 17	> 10	Sound condition. Low risk of fretting.	No action needed. A preventative maintenance treatment may be applied.
B	$17 \geq [T_{VET}] \leq 20$	≤ 10	Some age hardening. An increased risk of fretting.	Ideal condition. A preventative maintenance treatment should be applied.
C	> 20	≤ 10	Severely age hardened. High risk of fretting.	Preventative maintenance treatment not recommended.

Location	Product	Asphalt Type	Age since last resurfaced	Lab Sample ID	T(VET) (degree) - DSR	G*(VET) (MPa)- DSR	Table E/2.11 of CD227 Category
Jimmy Hill Way S2	Control	HRA	17+ years	26.0125	15.2	6.06	A-B
	PenTack	HRA	17+ years	26.0126	16.2	5.47	A-B
Auckland Drive	Control PenTack	HRA	9	26.0148	5.6	17.12	A
	PenTack	HRA	9	26.0149	6.6	16.57	A
	Control Reclamite	HRA	9	26.0150	1.7	27.95	A
	Reclamite	HRA	9	26.0151	4.6	18.24	A
A41 The Expressway	Control	HRA	13	26.0172	22.6	0.84	C
	PenTack	HRA	13	26.0173	16.5	1.75	A-B

Table 4. Rheological classification of binders extracted from HRA sections

Table 5. *Rheological classification of binders extracted from SMA sections*

5 Conclusions

Based on the laboratory testing and analysis of the core samples retrieved from various in-service HRA and SMA pavement sections and their recovered binders, the following conclusions have been drawn:

1. **Volumetrics and Binder Content:** The application of PenTack and Reclamite preservation treatments did not significantly alter the core asphalt mixture's binder content. Air voids analysis revealed localized filling or a sealing effect on open void structures, particularly within the SMA mixtures.
2. **Mechanical Performance:** The surface treatments maintained stiffness without weakening the asphalt surface. In the majority of SMA and HRA sections, the treated cores exhibited a moderate increase in structural stiffness compared to their untreated control counterparts.
3. **Sealing Efficacy against Water Ingress:** Hydraulic conductivity testing

Location	Product	Asphalt Type	Age since last resurfaced	Lab Sample ID	T(VET) (degree) - DSR	G*(VET) (MPa)-DSR	Table E/2.11 of CD227 Category
Jimmy Hill Way S1	Control	SMA	7	26.0123	18.1	7.44	B
	PenTack	SMA	7	26.0124	19.7	6.64	B
A452 Collector Road	Control PenTack	SMA	9	26.0152	25.4	5.12	C
	PenTack	SMA	9	26.0153	20.4	5.9	B
	Control Reclmite	SMA	9	26.0154	20.7	5.69	C
	Reclamite	SMA	9	26.0155	17.5	6.32	B
A41 the express way	Control	SMA	13	26.0146	25.8	8.26	C
	PenTack	SMA	13	26.0147	19.9	6.95	B
	Control	SMA	1	26.0174	17.5	7.83	B
	PenTack	SMA	1	26.0175	14.6	8.88	A-B
A4123 Wolverhampton Rd	Control	SMA	5	26.0176	18.9	5.32	B
	PenTack	SMA	5	26.0177	17.9	6.2	B
Longwood Lane	Control	SMA	6	26.0163	15.5	8.84	A-B
	PenTack	SMA	6	26.0164	15.5	10.46	A
Aldridge Road	Control	SMA	10	26.0161	25.3	5.67	C
	PenTack	SMA	10	26.0162	23.1	5.89	C

confirmed that both treatments are highly effective at sealing or penetrating into the voids of the permeable pavements. On highly open, severely aged roads, the relative hydraulic conductivity dropped significantly post-treatment, reducing the risk of moisture-induced damage.

4. **Restoration of Binder Properties:** Binders treated with Reclamite and PenTack consistently demonstrated increased penetration values and corresponding decreases in softening points, reversing the brittle characteristics associated with long-term oxidative ageing.
5. **Rheological classification:** DSR testing confirmed that the surface treatments softened the asphalt binder matrix. Under the CD227 rheological classification framework, multiple heavily aged control binders classified as Category C were upgraded into the more flexible Category B or A, confirming a significant restoration of binder viscoelastic properties to extend the remaining service life of the pavement.

6 Summary of Phase 1 and Phase 2

1. PenTack ***(Evaluated in Phase 1 & 2)***

- **Material Composition:** It is a cold spray-applied, modified bitumen emulsion-based technology.
- **Mechanical Behaviour:**
    - In Phase 1, the emulsion-based formulation acted as a softening agent, reducing core mixture stiffness (ITSM) by roughly 16% to 23% in highly aged Stone Mastic Asphalt (SMA) sections (e.g., Collector and Pickford WB).
    - In Phase 2, when evaluating performance on long-term aged in-service roads, it showed moderate enhancements in stiffness values across some pavement sections.
- **Sealing & Permeability:** PenTack proved highly effective in penetrating into voids of the permeable pavements. In Phase 1, it demonstrated the highest reduction in water uptake among all three options (ranging up to an 82% decrease in SMA). Phase 2 confirmed a profound drop in water infiltration, reducing relative

hydraulic conductivity significantly (e.g., dropping from 1304.7 mm/hr to 192.0 mm/hr at the A41 Expressway).

- **Binder Rejuvenation & Rheology:**
    - **Penetration Dynamics:** The lighter fractions of PenTack migrate into the asphalt, causing a significant reduction in binder stiffness (complex modulus, G*) in the lower sections of the cores.
    - **Rheological Shift:** It successfully softens heavily aged binders, shifting brittle "Category C" binders toward more flexible and elastic "Category B" or "Category A" classifications under the CD227 framework.
    - **Chemical Breakdown:** This shift is achieved by heavily replenishing the saturates chemical fraction of the aged asphalt.

2. Reclamite ***(Evaluated in Phase 1 & 2)***

- **Material Composition:** Reclamite is a spray-applied, oily maltene-based rejuvenator.
- **Mechanical Behaviour:**
    - Similar to PenTack, Reclamite works effectively as a softening agent. In Phase 1, it achieved a 16% reduction in mixture stiffness on Collector SMA sections by restoring the binder's flexibility.
    - In Phase 2, it exhibited a moderate increase in structural stiffness compared to untreated control samples on specific older roads.
- **Sealing & Permeability:** Reclamite provided strong protection against water ingress. It reduced water uptake in Phase 1 by approximately 57% to 58%. Phase 2 data echoed this efficiency, demonstrating a drop in water infiltration across highly permeable, older pavement surfaces.
- **Binder Rejuvenation & Rheology:**
    - **Penetration Dynamics:** Reclamite is highly penetrative, chemically interacting with and altering the chemistry of the existing bitumen matrix.
    - **Rheological Shift:** It consistently increases binder penetration values and decreases softening points, reversing bitumen embrittlement. Like PenTack, its lighter chemical components aggressively lower the crossover temperature, upgrading Category C binders into flexible operating brackets (Category B or A).

- **Chemical Breakdown:** Similar to PenTack, the rheological shift is achieved by heavily replenishing the saturates chemical fraction of the aged asphalt.

3. Rhinophalt ***(Evaluated in Phase 1)***

- **Material Composition:** Unlike the other two, Rhinophalt is a mineral antioxidant, Gilsonite resin-based cold spray-applied preservative.
- **Mechanical & Stiffness Behaviour:** * Instead of behaving primarily as an aggressive softening agent, Rhinophalt functions as a structural stabilizer and surface reinforcer.
    - Consequently, it results in slightly higher core mixture stiffness and lower core density than PenTack and Reclamite. While it did achieve stiffness reductions in specific SMA sections (e.g., Pickford EB and WB), the overall recovered binder stiffness remained roughly equal to or higher than the untreated controls.
- **Sealing & Permeability:** It successfully mitigates water ingress. It reduced water uptake by up to 60%–64% on the highly open SMA sections of Pickford EB and WB.
- **Binder Rejuvenation & Rheology:**
    - **Penetration Dynamics:** It demonstrates limited depth penetration compared to emulsion or maltene treatments. Instead, it provides a highly uniform stiffness profile throughout the depth of the core.
    - **Rheological Shift:** It typically maintains the binder's existing CD227 rheological category rather than modifying it to a softer category, because it avoids the addition of over-softening oily components.
    - **Chemical Breakdown:** Chemically, Rhinophalt selectively enriches the aromatic content of the binder. This keeps the Gaestel Index lower, which leads to a more colloidally stable, chemically balanced binder than saturate-heavy alternatives.

Overall**, PenTack and Reclamite** function as softening rejuvenators. They excel at restoring workability, reversing oxidative embrittlement, and dropping binder stiffness through the chemical shift in the saturate fractions. **Rhinophalt** behaves as a surface stabilizer. It relies on Gilsonite resin to enrich aromatics, protecting the surface layer against oxidation without risking the structural over-softening of the asphalt pavement.

REFERENCES

1. BS EN 12697-6:2018. *Bituminous mixtures – Test methods – Part 6: Determination of bulk density of bituminous specimens.*
2. BS EN 12697-26:2004. *Bituminous mixtures – Test methods – Part 26: Stiffness.*