Asphalt Preservation & Rejuvenation

CEDR Live Labs 2 South Campus

Report

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Executive Summary

As part of the CEDR Live Labs 2 South Campus project, the Nottingham Transportation Engineering Centre (NTEC) at the University of Nottingham was commissioned to evaluate the mechanical performance of three proprietary asphalt surfacing rejuvenators/preservatives such as PenTack, Reclamite and Rhinophalt in comparison with conventional untreated asphalt mixtures. The programme involved receiving 102 cores from two companies, Simtec and Colas, and from five different road sites: Collector, Auckland, Stivichall, Pickford EB, Pickford WB. The treated and untreated roads consisted of two types of asphalt mixtures: Stone Mastic Asphalt (SMA) and Hot Rolled Asphalt (HRA). Laboratory evaluations were conducted to determine the mixture density, IT-CY stiffness modulus and degree of saturation of the cores. Binder extraction and recovery from the top and bottom regions of the cores were undertaken and the recovered binder subsequently submitted to advanced rheological and SARA chemical analysis to further assess rejuvenator/preservative effectiveness.

The test results revealed distinct performance trends based on the material composition of the treatments. The inclusion of rejuvenators generally increased mixture density and reduced the stiffness modulus of the cores. Moreover, surface treated mixtures showed lower water uptake compared to untreated mixtures, indicating improved permeability resistance. The reduced stiffness in PenTack and Reclamite mixtures is attributed to their emulsion- and maltene-based formulations, which restore the aged binder's maltene content and improve flexibility with stiffness reductions of approximately 16-17% in the SMA sections. Rheological classification confirmed their capacity to shift aged binders from a brittle Category C toward a flexible Category A or B. Chemical analysis identified that this was achieved by significantly replenishing the saturates fraction.

In contrast, Rhinophalt (a Gilsonite resin-based binder) resulted in slightly higher stiffness and lower density compared to the rejuvenators (PenTack and Reclamite). While it provided similar stiffness reductions in specific sections (Pickford WB and Stivichall), it primarily functioned as a structural stabilizer rather than a softening agent. Rheologically, Rhinophalt often maintained the existing binder category but provided a more uniform stiffness profile throughout the core depth. Chemically, it selectively enriched the aromatic content, maintaining a lower Gaestel Index (Ic) and resulting in a more colloidally stable and chemically balanced binder than the saturate-heavy alternatives.

Furthermore, the study highlighted differences in penetration dynamics. While PenTack exhibited a more pronounced reduction in stiffness within the lower sections of the cores, indicating penetration of lighter fractions, Rhinophalt showed limited penetration and more consistent depth distribution. Overall, while all three treatments successfully reduced water permeability, the choice between them involves a trade-off: PenTack and Reclamite excel at restoring flexibility and workability through softening, while Rhinophalt

provides superior chemical stability and surface reinforcement without the risk of over-softening the asphalt layer.

1 Introduction

As part of the CEDR Live Labs 2 project, rejuvenator/preservative materials were utilised in road trials organised by the South Campus. Nottingham Transportation Engineering Centre (NTEC) was appointed to carry out a study assessing the mechanical performance, degree of saturation and effectiveness of rejuvenator/preservative materials such as PenTack, Reclamite and Rhinophalt. The scope of the study included measuring the densities of asphalt cores, stiffness modulus, assessing water uptake, and conducting rheological and chemical analyses on the extracted binders.

2 Materials

At NTEC, three different types of rejuvenated/preservation cores were received: PenTack, Reclamite, and Rhinophalt, along with untreated control cores. The material descriptions of these surface treatment materials are provided in Table 1. In total, 102 cores were received, including 62 cores from Simtec and 40 cores from Colas through TRL. These mixtures were installed on six different roads: Collector, Auckland, Stivichall, Pickford EB, and Pickford WB, and included different mix designs such as stone mastic asphalt (SMA), and hot rolled asphalt (HRA). The NTEC log entries for all cored samples from both companies are provided in Appendix A, and the core photographs supplied by Simtec and Colas are also included in Appendix A. At NTEC lab, the samples received from different roads were labelled with a specific identification number as listed in Appendix B.

Table 1: Material description of surface treatment materials

S.No	Product	Material Description
1	PenTack   	PenTack is a bitumen emulsion-based product that is applied cold. It consists of a regenerating emulsion and a modified bitumen emulsion mixed with water. These three components are adjustable during application thus ensuring a unique product mix that matches the varying conditions of the asphalt surface. Finally, a fine aggregate is sprayed on the treated areas. The fine aggregate and the binder then form new asphalt mortar and restores the microstructure of the surface. The size and type of the aggregate depend on the area and use of the asphalt. PenTack is a pavement preservation and rejuvenation technique that is used to extend the service life of asphalt pavements by up to 6 years. The treatment system replaces some or all of the binder mastic (bitumen + fine aggregate) that has been eroded from the existing asphalt surface over time.
2	Reclamite	Reclamite is a maltene-based asphalt preservation treatment that extends pavement life by restoring essential chemical components lost during manufacturing and through oxidation. Reclamite is a spray applied rejuvenation treatment which

	 	penetrates and chemically modifies the bitumen binder in the asphalt. It reverses the detrimental impact on our roads caused by oxidation and weathering, preventing the formation of cracks and defects, and prolonging the life of the asphalt.
3	Rhinophalt  	Rhinophalt is a Gilsonite fortified cold spray-applied penetrative asphalt preservative. Gilsonite is a mineral antioxidant and is a key component in preventing asphalt deterioration caused by oxidation of the bitumen. Rhinophalt is best utilised as a preventative maintenance or protective measure as part of a long-term asset management strategy, extending the service life of the asphalt surface course and significantly delaying the need for reactive maintenance and resurfacing.

3 Laboratory Testing Programme

After receiving the cores for the three-rejuvenator/preservative surface treated mixtures and untreated mixtures, they were subjected to a sequence of tests as shown in Figure 1:

1. The **bulk densities** of the cored specimens were measured in accordance with *BS EN 12697-6:2020*.
2. The cored specimens were then tested for **indirect tensile stiffness modulus (IT-CY)** in accordance with *BS EN 12697-26:2004*.
3. The same specimens were tested for **degree of saturation/water uptake** using an internal NTEC protocol.
4. The specimens were then cut into two halves (top and bottom layers), and binder extraction and recovery performed on the different asphalt layers. The **recovered binders** was subsequently subjected to DSR complex modulus testing and SARA chemical fractionation analysis.
5. The efficiency of the rejuvenators/preservatives was then evaluated by subjecting the recovered binders to DSR testing and comparing the **complex modulus** values of binders recovered from the top and bottom sections of the cored specimens.
6. The recovered binders were then subjected to **SARA chemical fractionation** analysis.

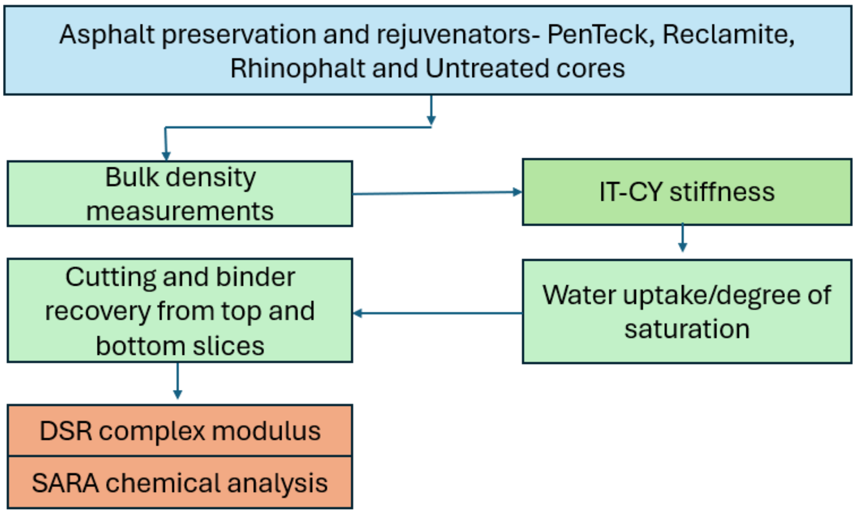


Figure 1. Testing programme

3.1 Density Measurements

The bulk density of the cored specimens was measured in accordance with BS EN 12697-6:2018. The cores used for testing were approximately 150 mm in diameter and 40 mm in thickness, with an approximate mass of 1500 g. The measured densities of all samples ranged between 2.1 and 2.5 Mg/m^3. Details of specimen volumetrics, and NTEC test data sheets are provided in Appendix C.

3.2 Indirect Tensile Stiffness Modulus (IT-CY)

The surface treated and untreated core specimens were subjected to non-destructive IT-CY testing in accordance with BS EN 12697-26:2004 for stiffness determination. Details of the testing setup, specimen volumetrics, and NTEC test data sheets are provided in Appendix C. The influence of different types of surface treatments on the stiffness and density of asphalt mixtures is discussed in the following section.

3.3 Degree of Saturation/ Water Uptake

The water ingress through asphalt samples was assessed using a newly developed testing protocol (See Appendix D). The asphalt samples were wrapped with aluminum foil around their sides to prevent lateral water penetration and placed top surface down on a grill submerged in water. The wrapped samples were then subjected to controlled vacuum saturation conditions for 30 minutes at a pressure of 600 mBar and a temperature of 20°C. During this process, a vacuum was applied to reduce the atmospheric pressure from approximately 1000 mBar to 600 mBar, promoting the removal of entrapped air within the sample voids and allowing water to infiltrate effectively into the top surface of the cores as shown in schematic Figure 2. The difference in mass before and after saturation was recorded as the water uptake value (in grams). Details of specimen mass before and after saturation are provided in Appendix D.

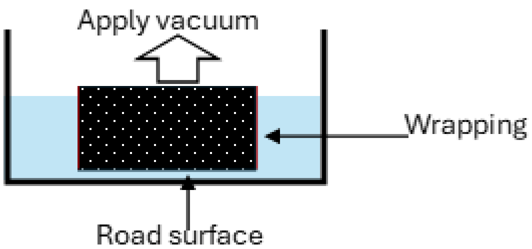


Figure 2: Schematic of asphalt water saturation method

3.4 Complex Modulus of Recovered Binders

After measuring water uptake, the samples (40mm thick) were cut into two portions: top (17mm), wasted material associated with saw blade (6mm), and bottom (17mm). The binders were extracted from top and bottom sliced samples. The binders were extracted using a solvent-based extraction and recovered using rotary evaporation method in accordance with BS EN 12697-3. To determine the complex modulus, the recovered binders were subjected to frequency sweep tests (See Appendix E). An 8 mm plate was used for temperatures between 5°C and 40°C, covering frequencies from 0.1 to 10 Hz. A 25 mm plate was used for higher temperatures between 30°C and 75°C, over the same frequency range of 0.1 to 10 Hz. During testing, the storage modulus and loss modulus were measured. These values were used to calculate the complex modulus (G*) and phase angle. The complex modulus (G*) indicates the stiffness of the binder, while the phase angle (δ) describes its viscoelastic behaviour, where values closer to 0° indicate more elastic (solid-like) behaviour and values closer to 90° indicate more viscous (fluid-like) behaviour. The master curves were constructed at a reference temperature of 25°C.

3.5 SARA Fractionation

To determine the chemical composition of the bitumen, a Saturates, Aromatics, Resins and Asphaltenes (SARA) fractionation procedure was conducted by first precipitating asphaltenes from a 400 mg sample using 40 mL of n-heptane. The bitumen and n-heptane were stirred for 24 hours at 200 rpm to ensure complete dissolution of bitumen, followed by filtration through 0.22 µm PTFE filters to isolate the maltene phase. The asphaltene content was calculated by mass difference after drying the maltenes using an oven programme reaching 135°C for 2hrs. The remaining maltenes were then loaded onto a 5 g silica gel SPE cartridge to separate the saturates, aromatics, and resins (See Appendix F). Selective elution was performed using n-heptane for saturates, a toluene/n-heptane (80:20) blend for aromatics, and a DCM/methanol (90:10) blend for resins. Finally, each fraction was dried and weighed to calculate its respective percentage relative to the total bitumen mass (Sakib and Bhasin, 2019).

4 Test Results, Analysis and Discussion

4.1 Density Measurements

The individual densities of all core specimens are presented in Figure 3, while the densities (average and standard deviation) of the different sets of cores before and after treatment are shown in Figure 4. As can be seen in Figure 4b, the density increase after surface treatment of the PenTack-treated samples are generally higher than those seen for the Reclamite and Rhinophalt treated samples. The increase in density of the treated (rejuvenator/preservative) samples can be assumed to be due to the surface treatment penetrating into the void structure of the different surfacing materials. The density values of all samples are provided in Appendix C.

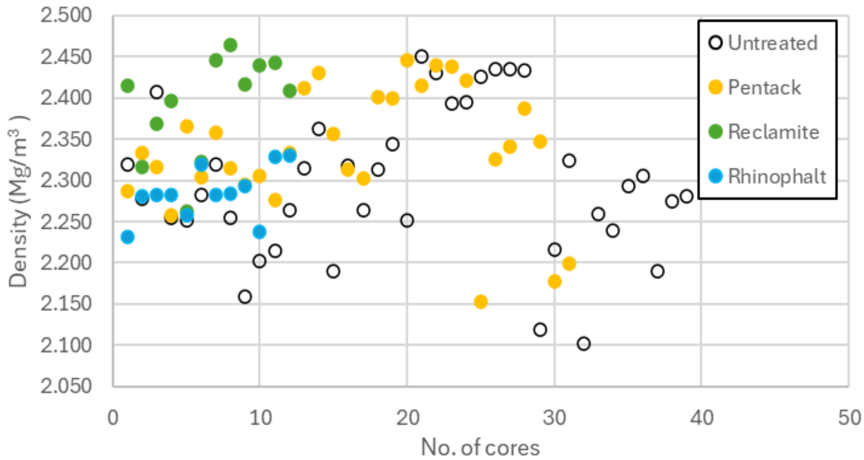


Figure 3. Densities of all surface treated and untreated asphalt cores

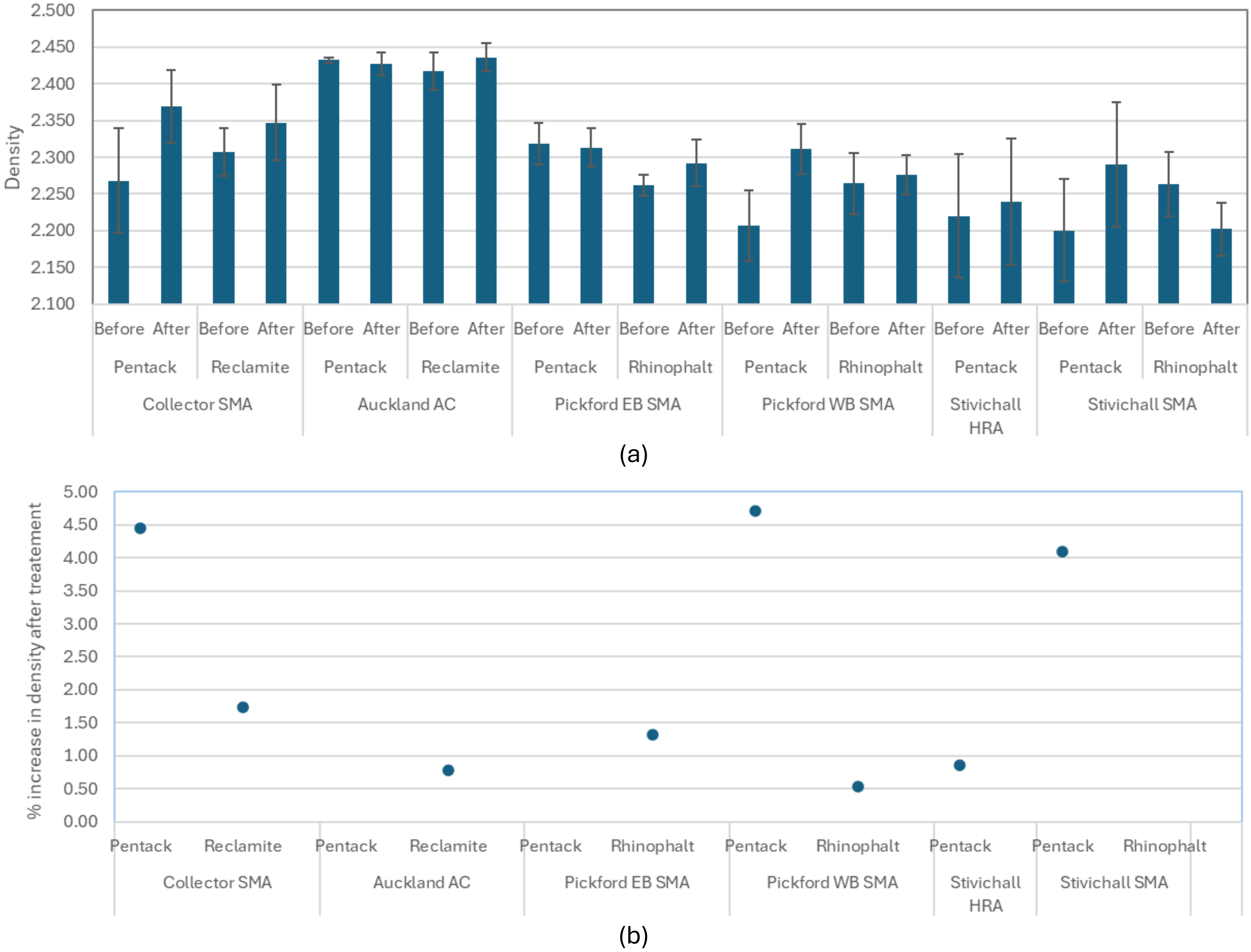


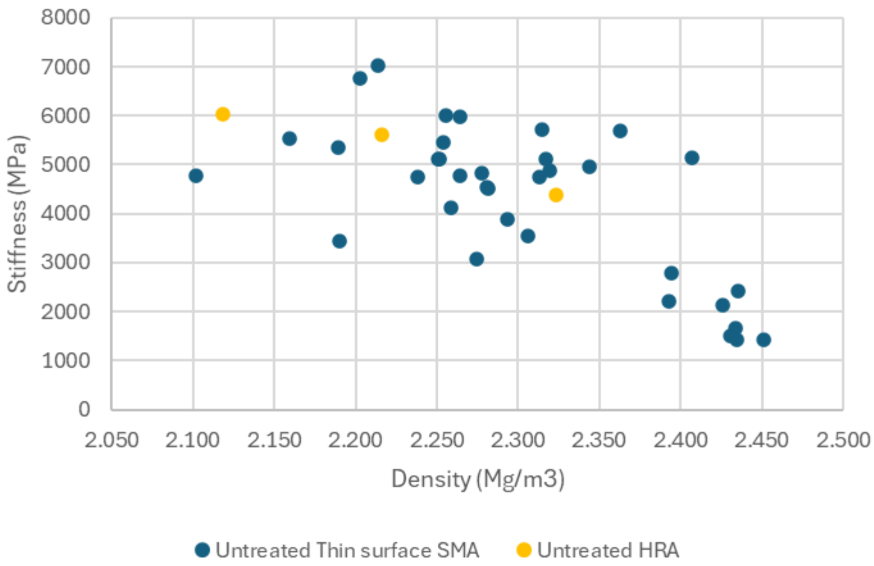
Figure 4. Average densities of asphalt cores before and after surface treatments

4.2 Indirect Tensile Stiffness Modulus (IT-CY)

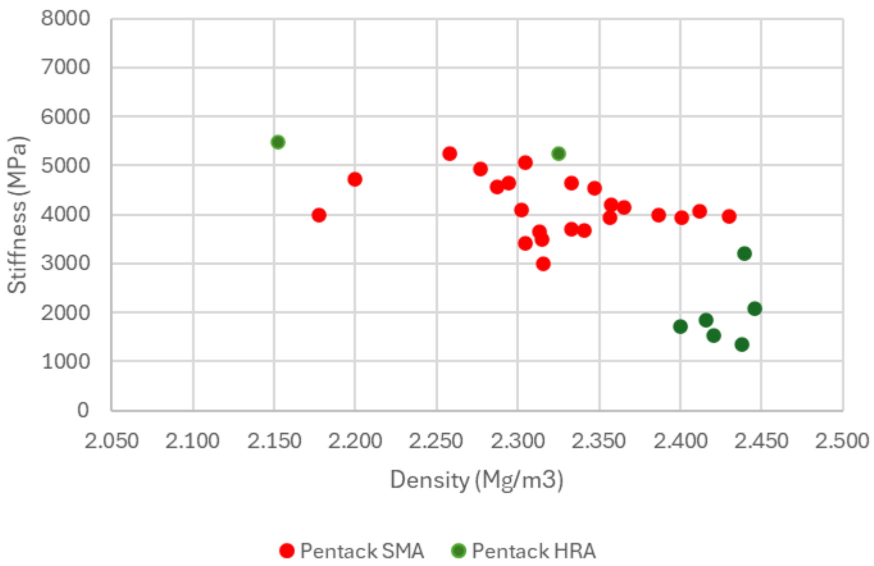
Figure 5 shows the stiffness of all untreated, PenTack, Reclamite, and Rhinophalt treated samples for the different roads. The surface treated cores were obtained from different roads and consist of SMA and HRA asphalt mixtures. The cores received from TRL for untreated mixtures were designated as thin surfacing and contained SMA. Among the surface-treated samples shown in Figures 5c–d, the density of the HRA samples was higher than that of the SMA samples, and the SMA samples exhibited higher stiffness values than the HRA samples in most cases.

Figure 6 presents the stiffness of all three treated samples along with the untreated control samples. For each road, the average stiffness of treated samples along with their control untreated samples are shown in Figure 7. The stiffness and density values of each sample are provided in Appendix C. The surface treatments applied to SMA sections tend to lead to a reduction in stiffness; however, this effect was not seen in the HRA mixtures.

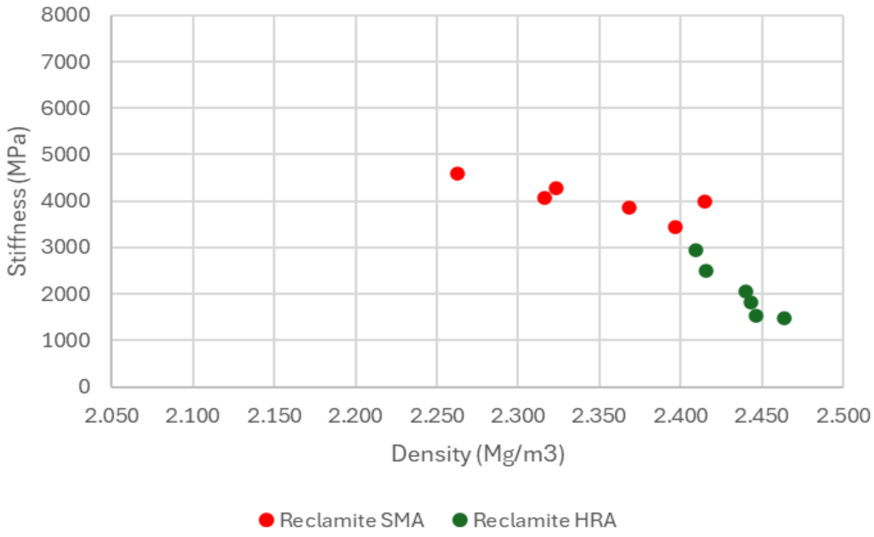
On the Collector Road, the reductions in stiffness achieved by PenTack and Reclamite were approximately the same (Table 2). While on Pickford WB, PenTack was more effective in reducing the stiffness, and on Pickford EB and Stivichal SMA, Rhinophalt significantly reduced stiffness.



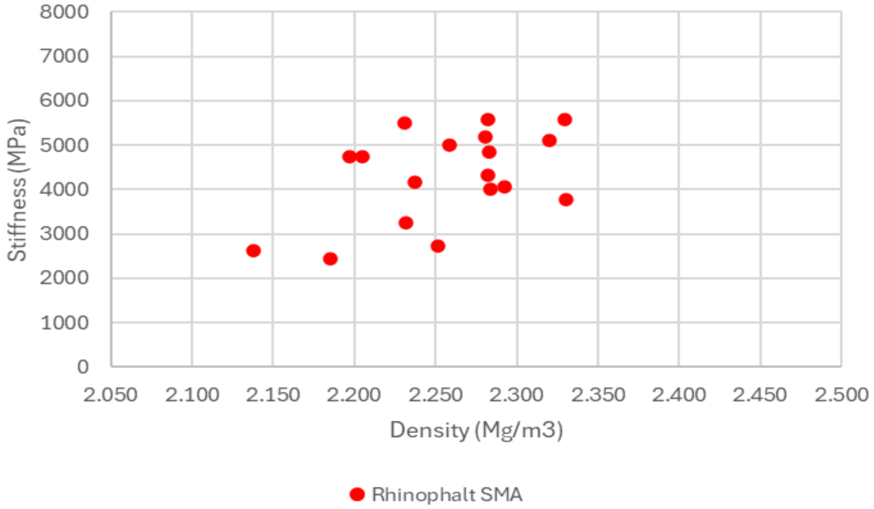
(a)



(b)



(c)



(d)

Figure 5. Stiffness of asphalt cores received from roads with different mix designs (a) untreated, (b) PenTack, (c) Reclamite, (d) Rhinophalt

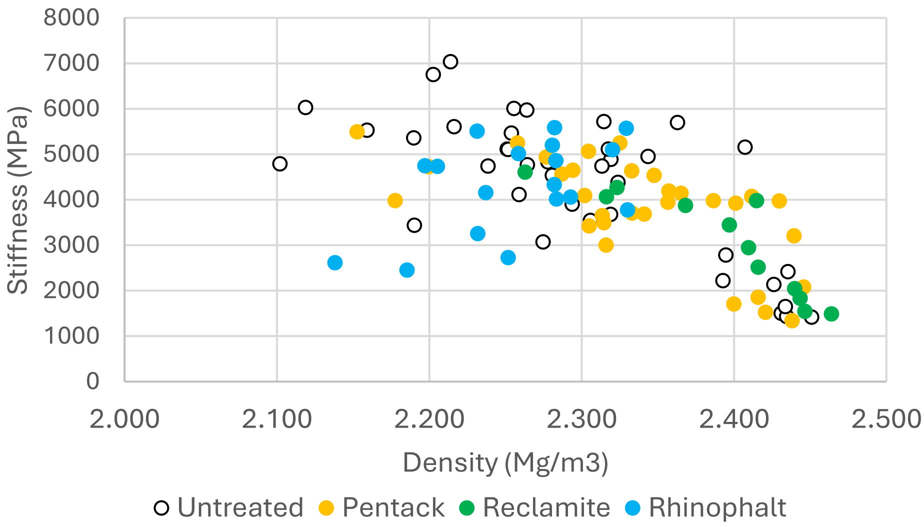
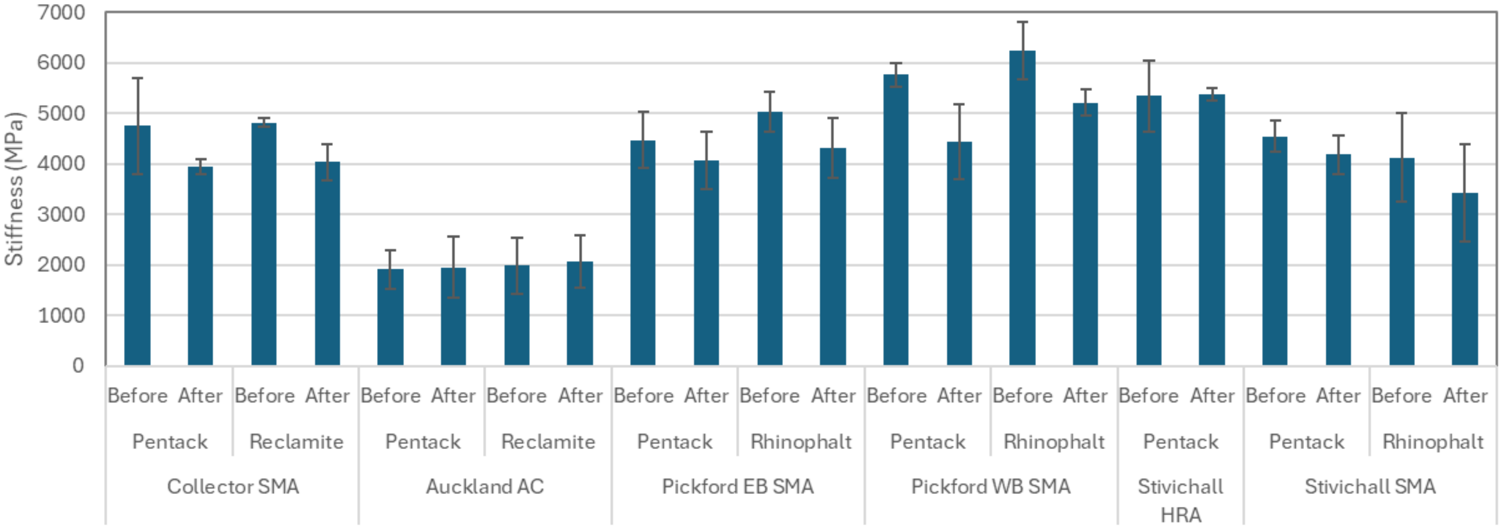
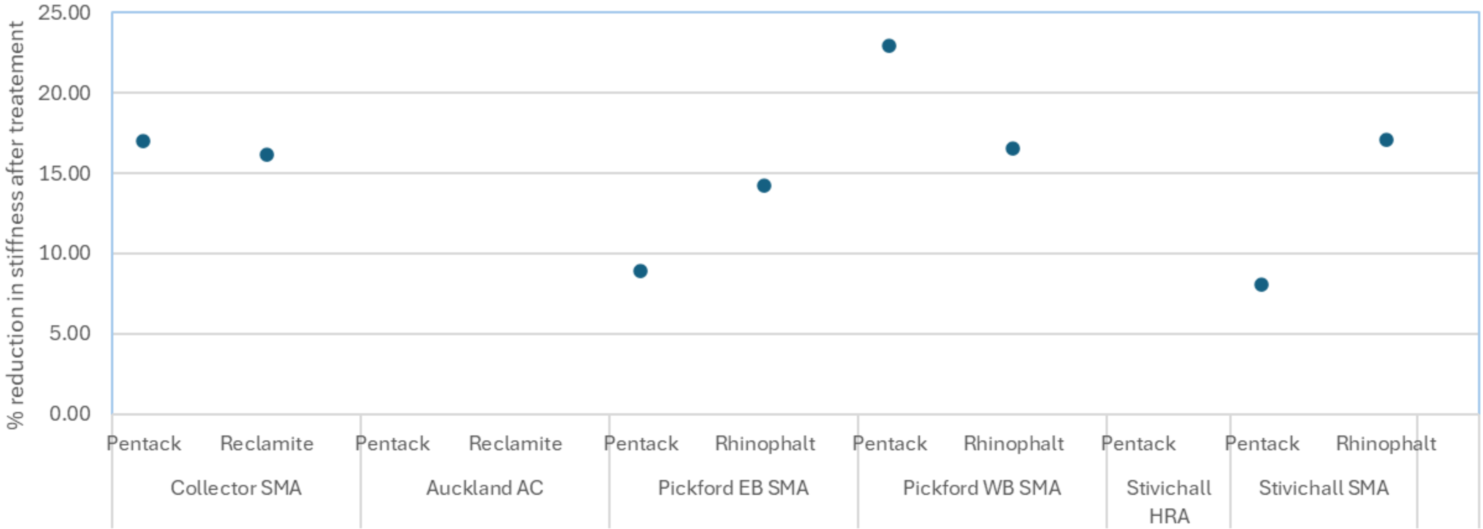


Figure 6. Stiffness values of all treated and untreated asphalt cores



(a)



(b)

Figure 7. (a) Average stiffness values before and after treatments, (b) % decrease in stiffness after treatments.

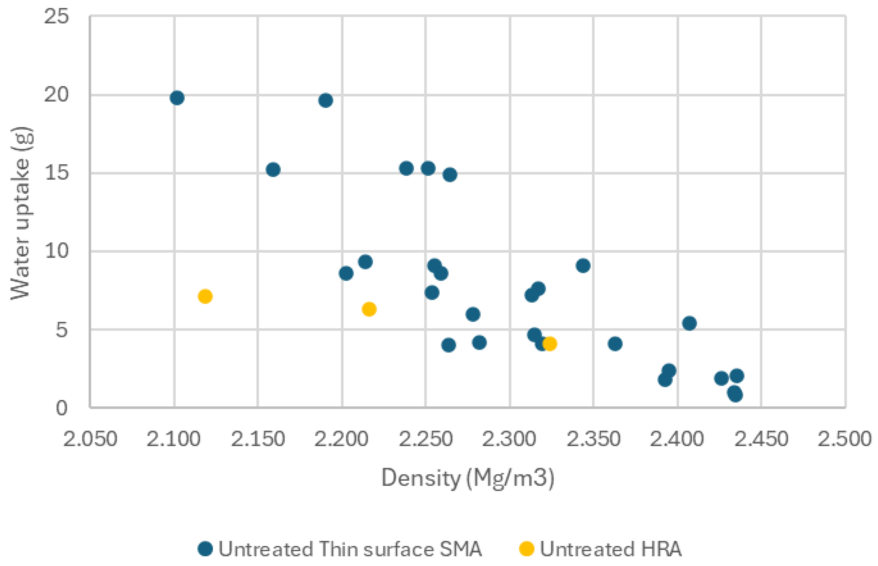
Table 2. Average stiffness values of cores before and after treatments

Road	Treatment	Condition	Avg stiffness	SD	% decrease in stiffness
Collector SMA	PenTack	Before	4747	958	16.98
		After	3941	144	
	Reclamite	Before	4819	95	16.19
		After	4039	355	
Auckland HRA	PenTack	Before	1910	389	-2.20
		After	1952	607	
	Reclamite	Before	1981	557	-3.99
		After	2060	521	
Pickford EB SMA	PenTack	Before	4465	557	8.91
		After	4067	576	
	Rhinophalt	Before	5034	388	14.26
		After	4316	585	
Pickford WB SMA	PenTack	Before	5765	240	22.95
		After	4442	736	
	Rhinophalt	Before	6241	568	16.54
		After	5209	259	
Stivichall HRA	PenTack	Before	5339	700	-0.51
		After	5366	123	
Stivichall SMA	PenTack	Before	4546	308	8.07
		After	4179	387	
	Rhinophalt	Before	4126	885	17.11
		After	3420	963	

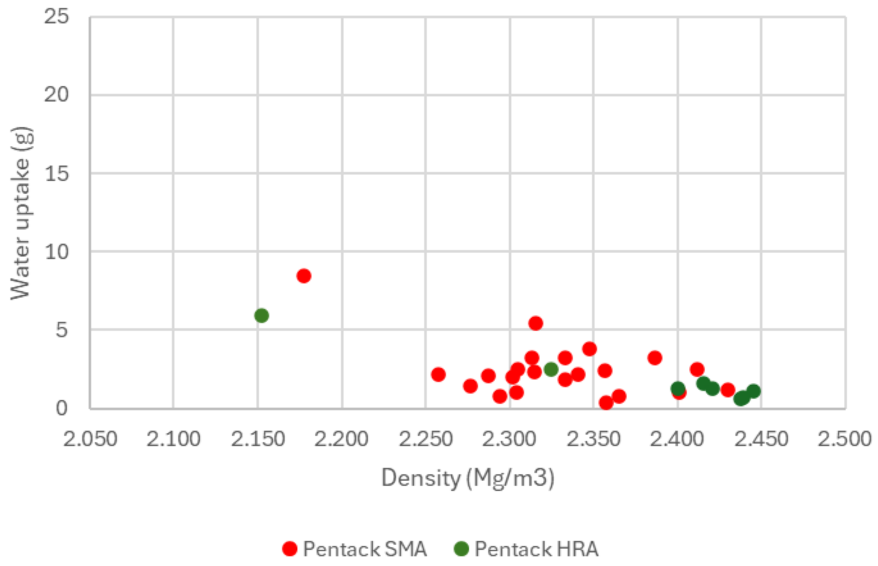
4.3 Water Uptake

Figure 8 show the water uptake in the untreated, PenTack, Reclamite, and Rhinophalt treated samples. Among the surface-treated samples shown Figure 8b-d, the HRA samples exhibited lower water uptake and higher densities than the SMA samples.

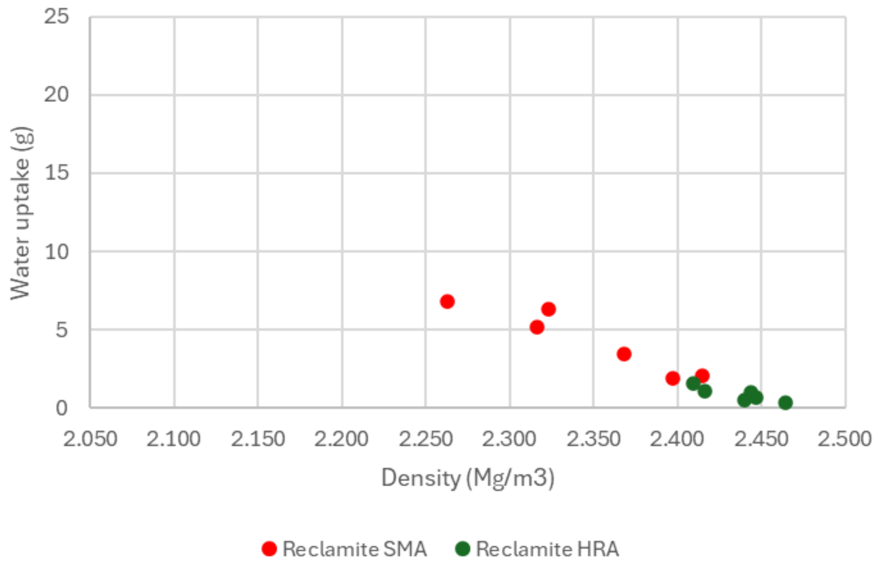
Figure 9 presents the water uptake of all treated samples along with the untreated control samples for all roads. The average water uptake values and their percentage decrease after treatment are shown in Figure 10 and Table 3, while the detailed water uptake data for each sample are provided in Appendix D. In most SMA sections, the average water uptake of the PenTack samples was lower than that of the Reclamite and Rhinophalt samples. This indicates that all surface treatments reduced the water permeability of the samples, with PenTack being the most effective. This superior performance may be attributed to the material composition of the treatments: PenTack is an emulsion-based technology, Reclamite is a maltene-based rejuvenator and Rhinophalt is a Gilsonite resin based preservative. These treatments contributed to restoring the aged asphalt binder, improving binder cohesion, and minimizing moisture ingress within the mixture.


Water uptake (g)
25
20
15
10
5
0
2.050
2.100
2.150
2.200
2.250
2.300
2.350
2.400
2.450
2.500
Density (Mg/m3)
Untreated Thin surface SMA
Untreated HRA

(a)


Water uptake (g)
25
20
15
10
5
0
2.050
2.100
2.150
2.200
2.250
2.300
2.350
2.400
2.450
2.500
Density (Mg/m3)
Pentack SMA
Pentack HRA

(b)



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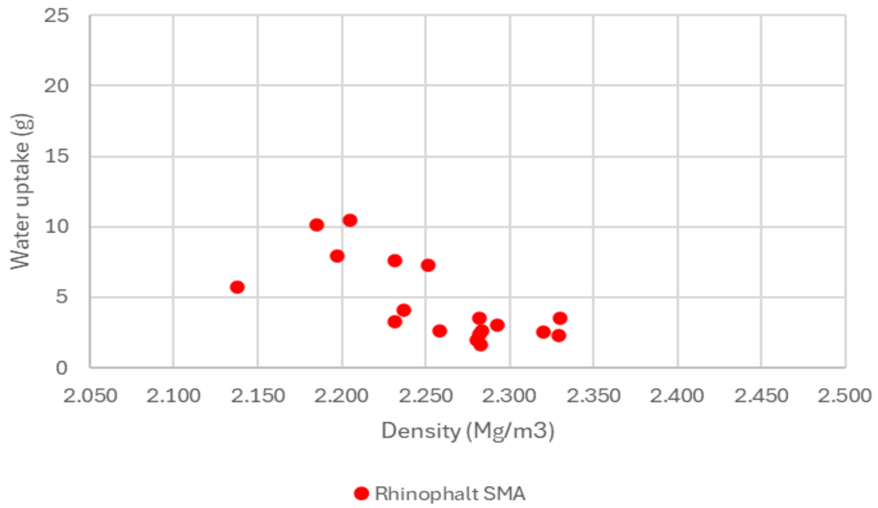


(d)

Figure 8. Water uptake in asphalt cores received from roads with different mix designs (a) untreated, (b) PenTack, (c) Reclamite, (d) Rhinophalt

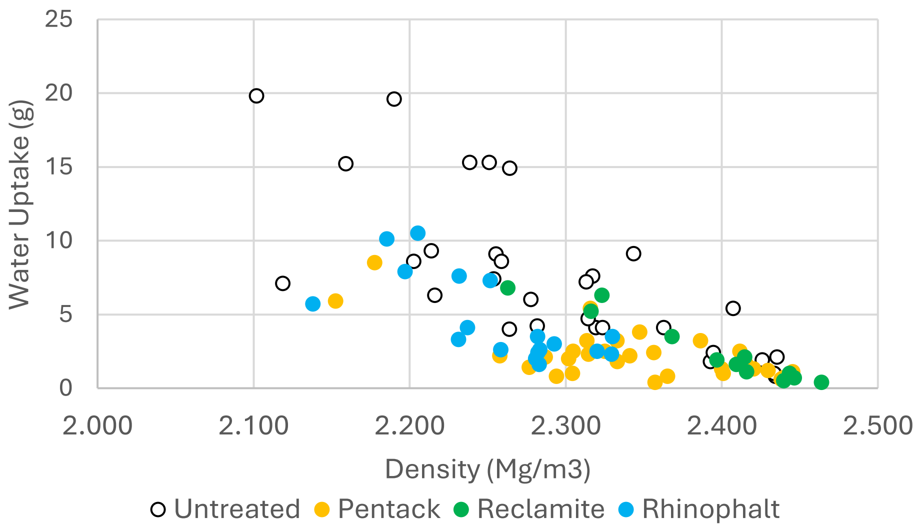
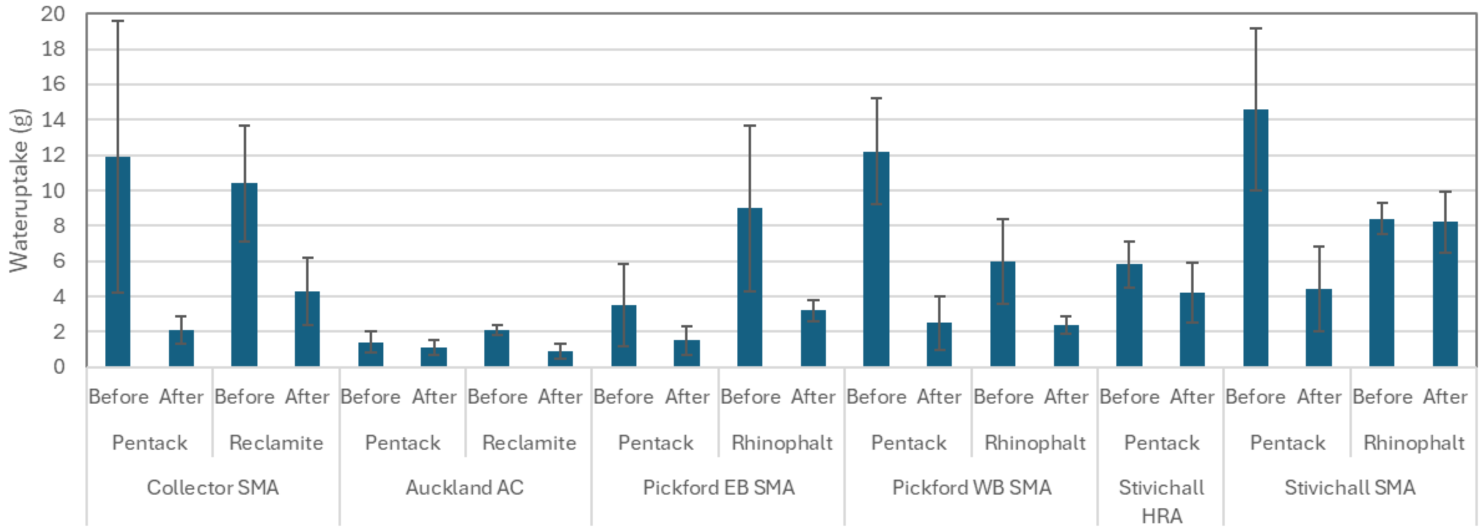
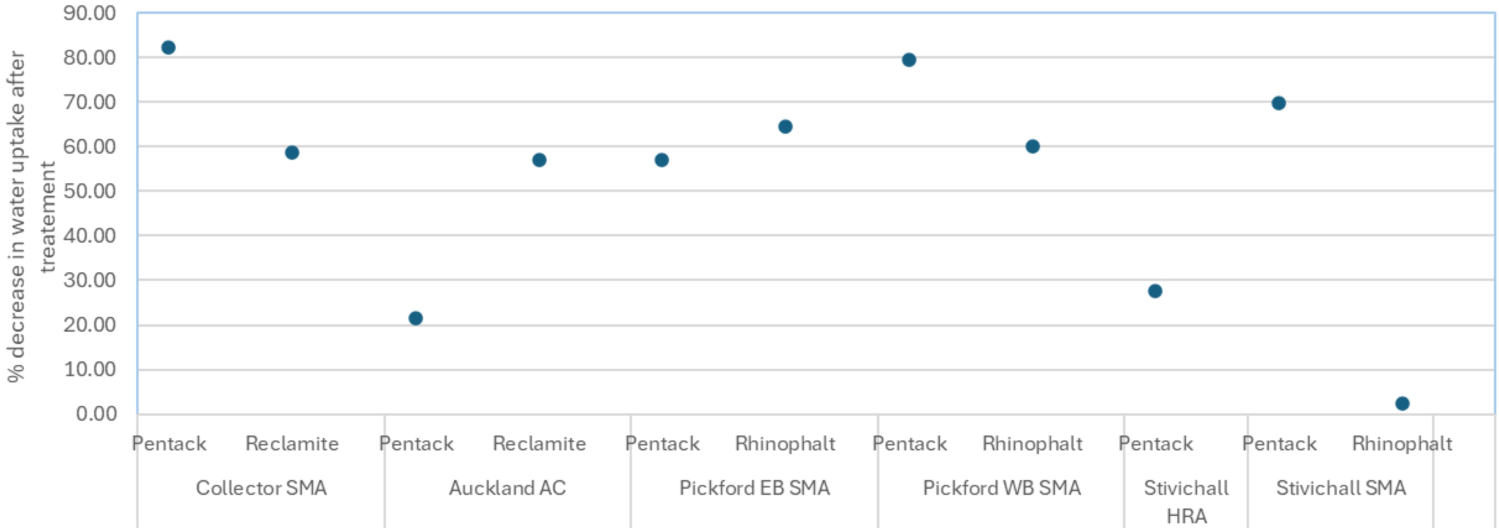


Figure 9. Water uptake in all treated and untreated asphalt cores



(a)



(b)

Figure 10. (a) Average water uptake values before and after treatments, (b) % decrease in water uptake after treatments

Table 3. Average water uptake values of cores before and after treatments

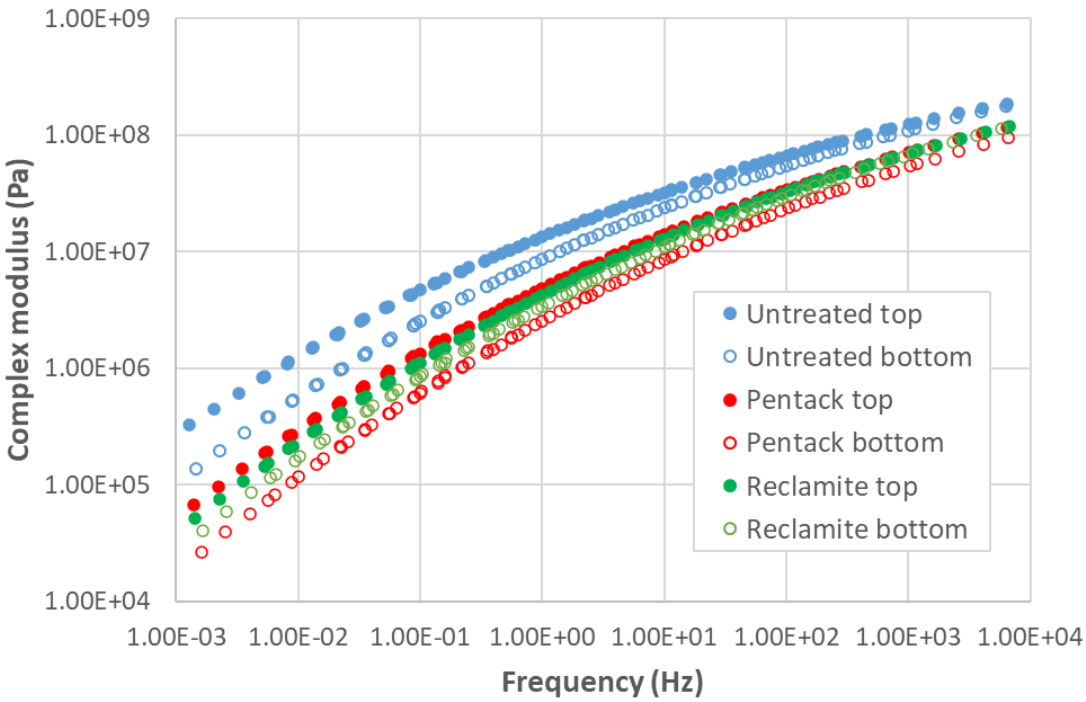
Road	Treatment	Condition	Avg water uptake	SD	% decrease in water uptake
Collector SMA	PenTack	Before	11.9	7.7	82.35
		After	2.1	0.8	
	Reclamite	Before	10.4	3.3	58.65
		After	4.3	1.9	
Auckland HRA	PenTack	Before	1.4	0.6	21.43
		After	1.1	0.4	
	Reclamite	Before	2.1	0.3	57.14
		After	0.9	0.4	
Pickford EB SMA	PenTack	Before	3.5	2.3	57.14
		After	1.5	0.8	
	Rhinophalt	Before	9	4.7	64.44
		After	3.2	0.6	
Pickford WB SMA	PenTack	Before	12.2	3	79.51
		After	2.5	1.5	
	Rhinophalt	Before	6	2.4	60.00
		After	2.4	0.5	
Stivichall HRA	PenTack	Before	5.8	1.3	27.59
		After	4.2	1.7	
Stivichall SMA	PenTack	Before	14.6	4.6	69.86
		After	4.4	2.4	
	Rhinophalt	Before	8.4	0.9	2.38
		After	8.2	1.7	

4.4 Stiffness of Recovered Binders

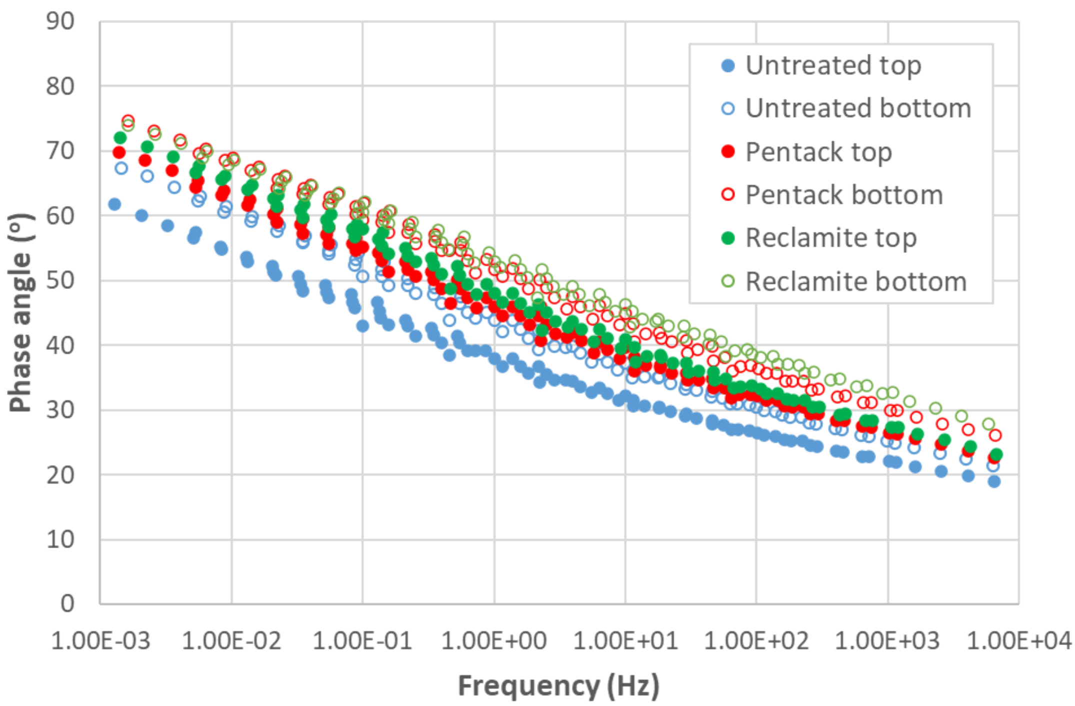
To evaluate the efficiency of the rejuvenators/preservatives, the complex modulus (G*) and phase angle (δ) of binders recovered from the top and bottom sections of the cored specimens were measured. For both untreated and treated samples, the binders extracted from the top portion exhibited higher stiffness than those from the bottom portion (Figure 11 to Figure 15). At 1Hz frequency (Figure 16 & Table 4), the complex moduli of the Pentack and Reclamite samples were approximately equal; however, Rhinophalt exhibited higher moduli than the Pentack samples. This difference is likely attributed to their respective formulations: Rhinophalt is a resin-based binder containing Gilsonite, whereas Pentack is an emulsion-based material. This resinous composition inherently provides greater stiffness compared to the oily, emulsion-based rejuvenators.

In the case of untreated binders, the difference in moduli between top and bottom regions is likely attributable to aging of the binder at the surface. As shown in Table 4, in the treated mixtures, Pentack exhibited a more pronounced reduction in binder stiffness within the bottom portion of the core. In contrast, Rhinophalt demonstrated a relatively uniform stiffness profile throughout the entire depth. This variance reflects the penetration dynamics, where the lighter fractions of the emulsion-based Pentack migrate deeper into the asphalt, whereas the resin-based Rhinophalt provides a more consistent, surface-stabilizing effect.

Overall, the stiffness trends observed for the binders were consistent with those of the corresponding mixtures. The stiffness values of the untreated and Rhinophalt-treated binders were approximately equal as can be seen in Figure 13 to Figure 15. Among the rejuvenated/preservation samples, Rhinophalt exhibited higher stiffness than PenTack and Reclamite (Figure 11 to Figure 12).

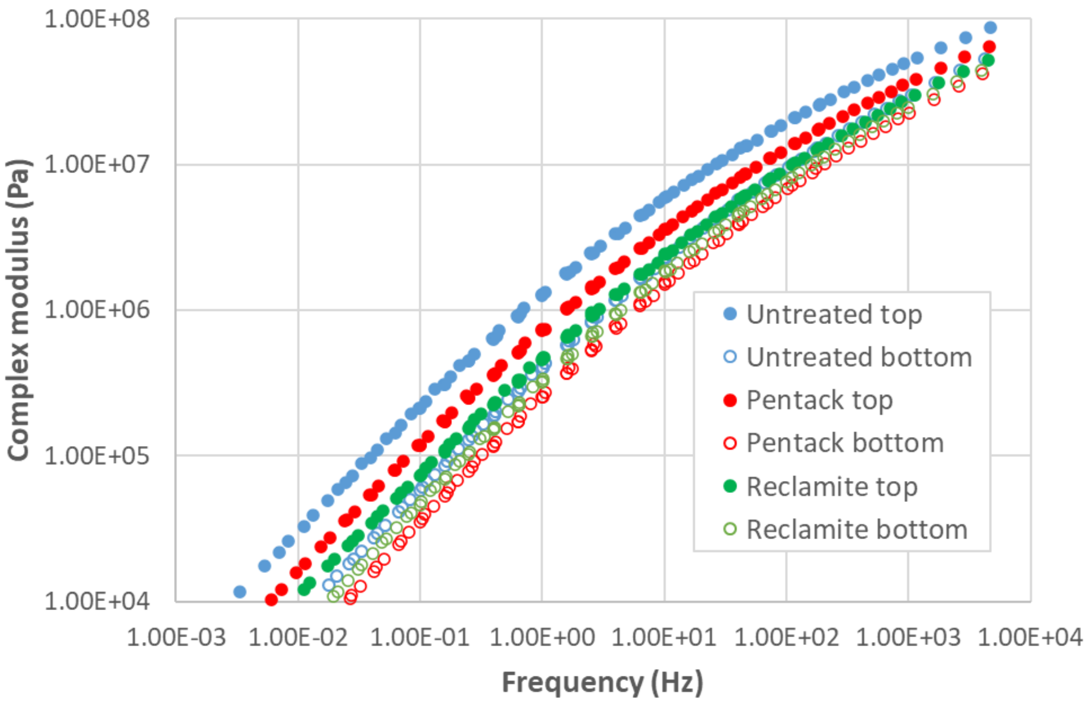


(a) Complex modulus

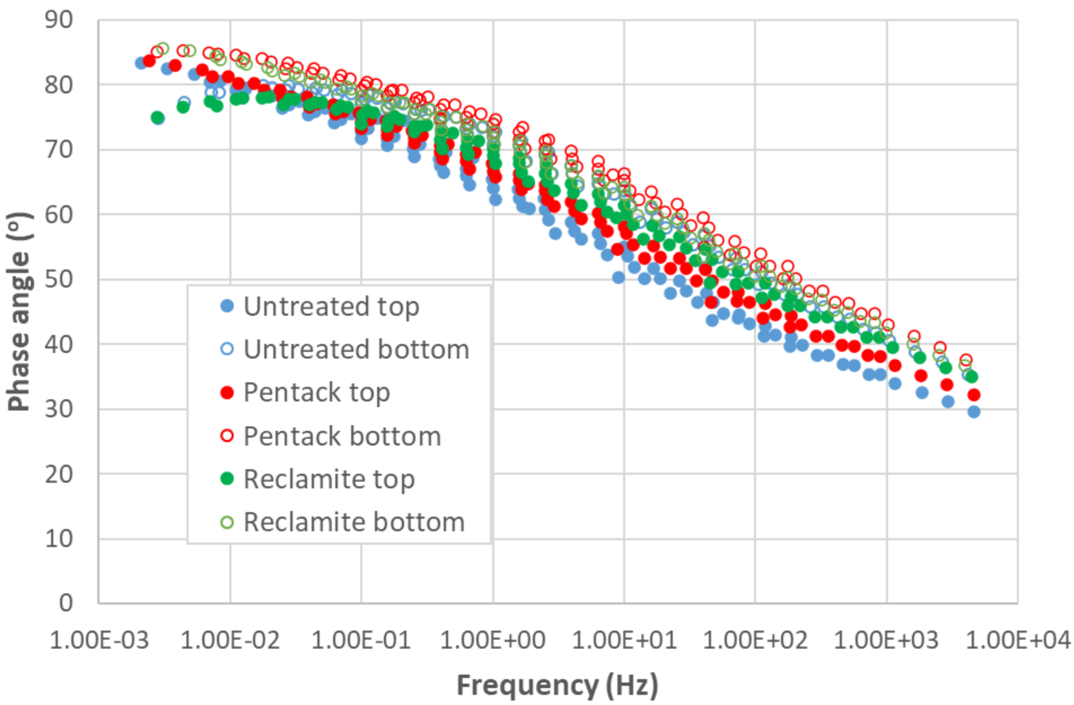


(b) Phase angle

Figure 11. G and δ of Collector Road* (Untreated > PenTack > Reclamite)

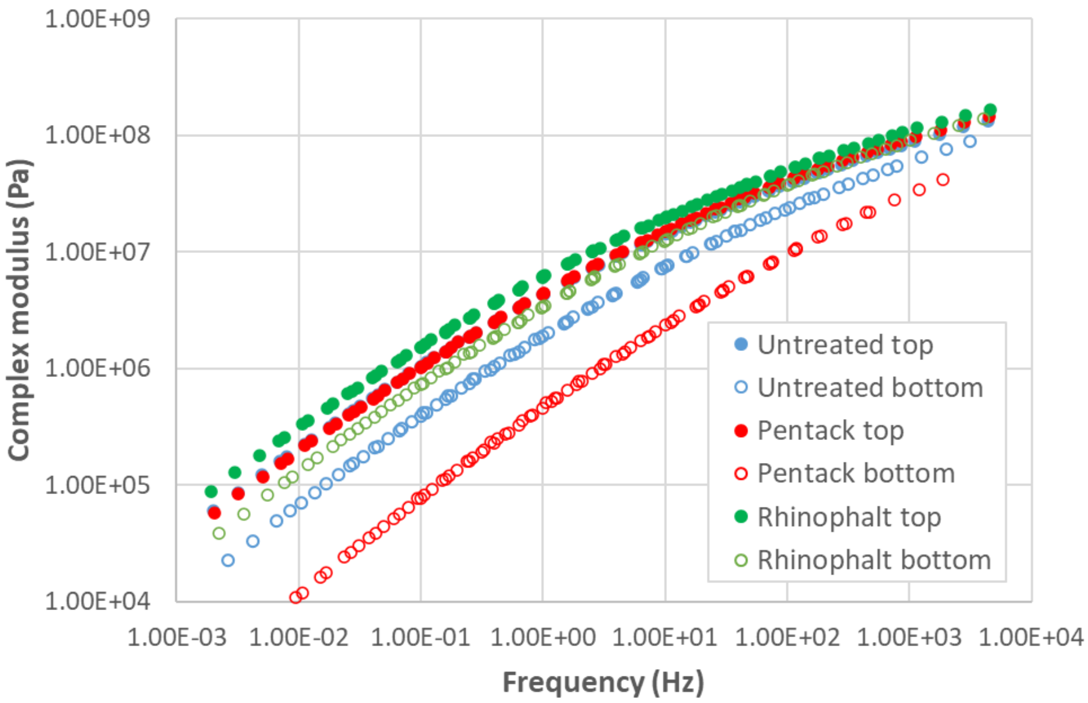


(a) Complex modulus

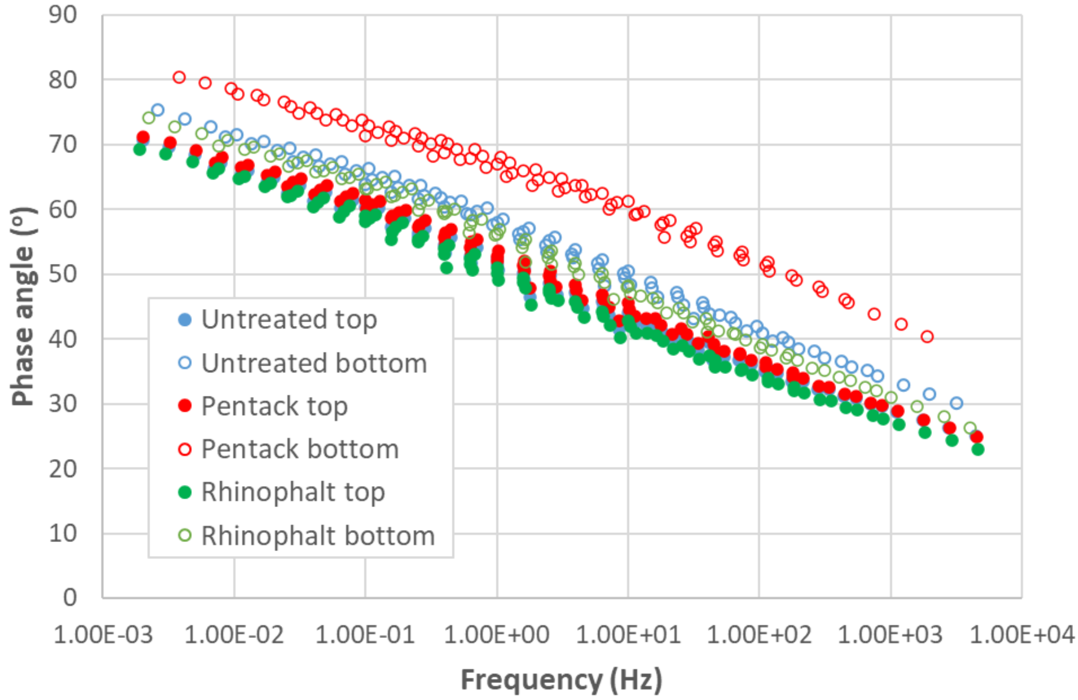


(b) Phase angle

Figure 12. G and δ of Auckland road* (Untreated > PenTack > Reclamite)

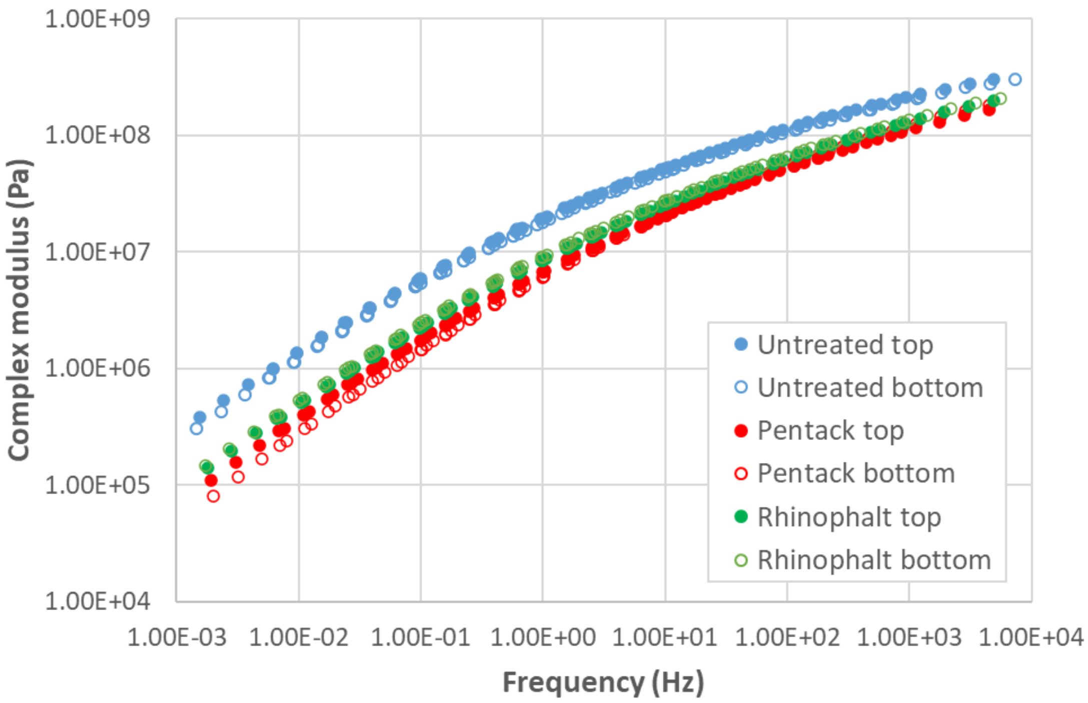


(a) Complex modulus

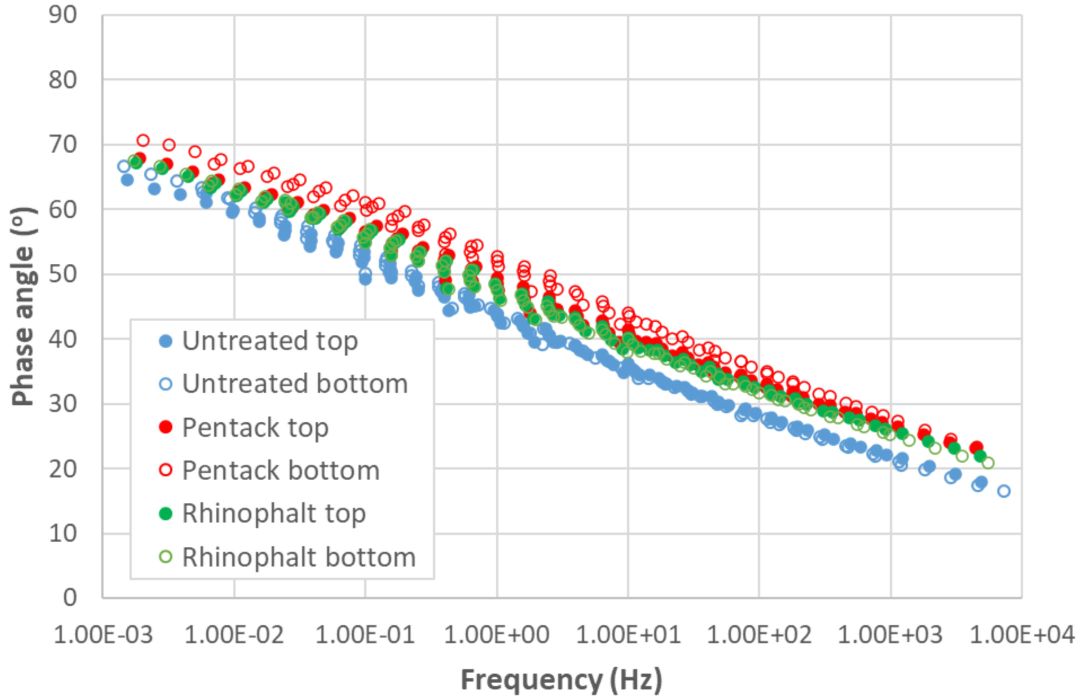


(b) Phase angle

Figure 13. G and δ of Pickford EB* (Rhinophalt> Untreated> PenTack)

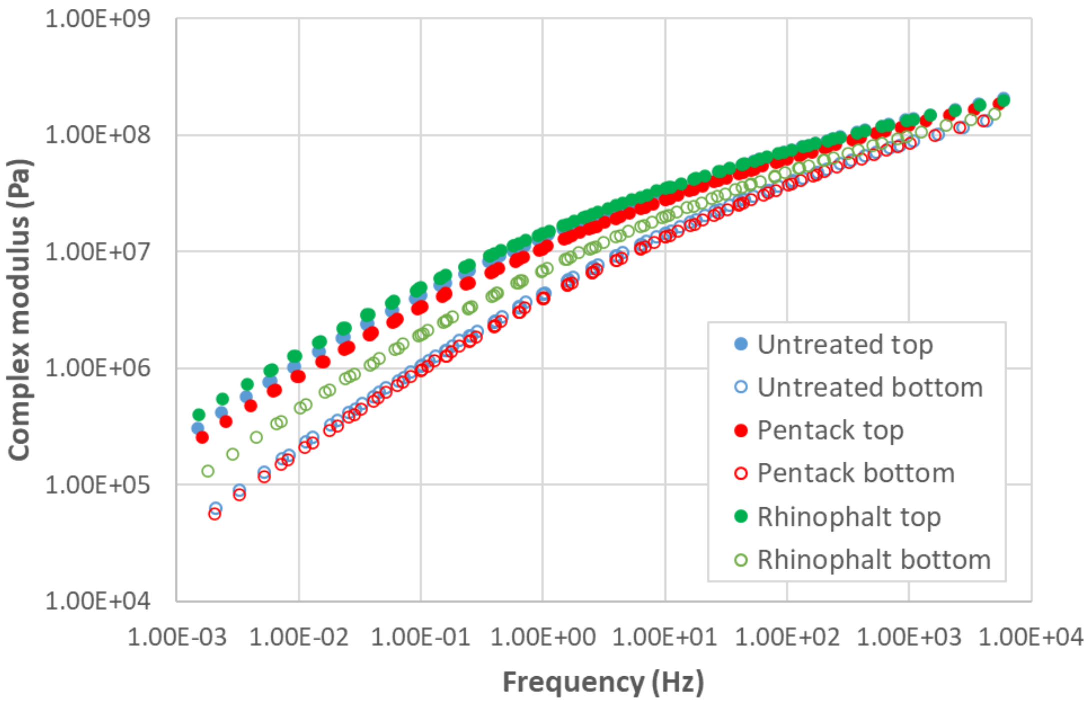


(a) Complex modulus

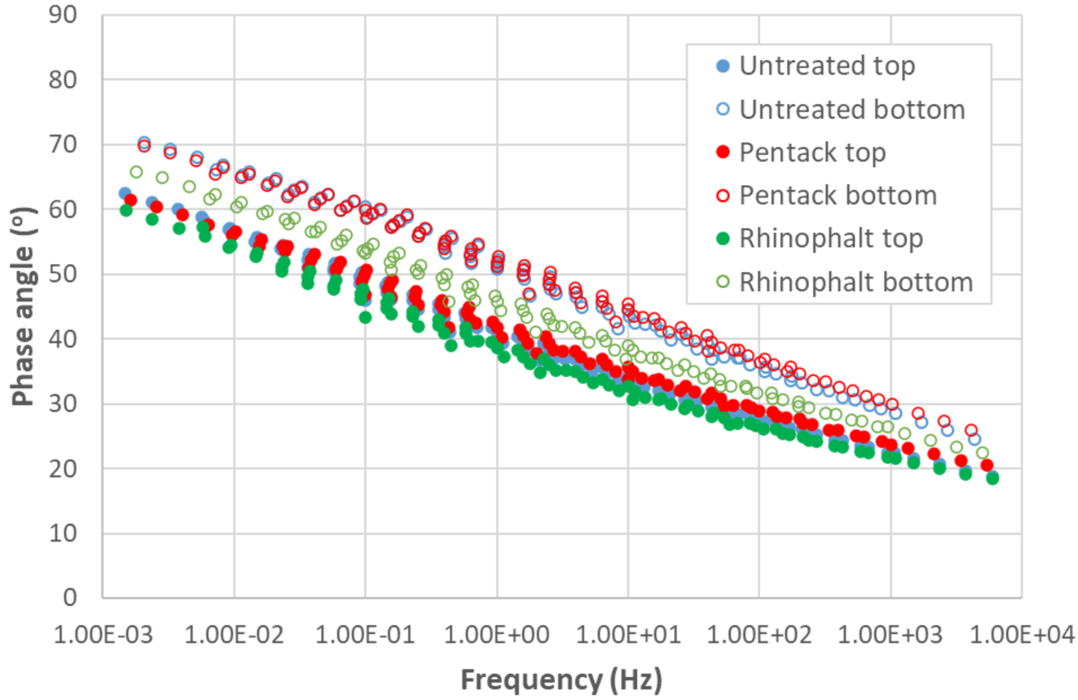


(b) Phase angle

Figure 14. G and δ of Pickford WB* (Untreated> Rhinophalt> PenTack)



(a) Complex modulus



(b) Phase angle

Figure 15. G and δ of Stvichall* (Rhinophalt≥ Untreated> PenTack)

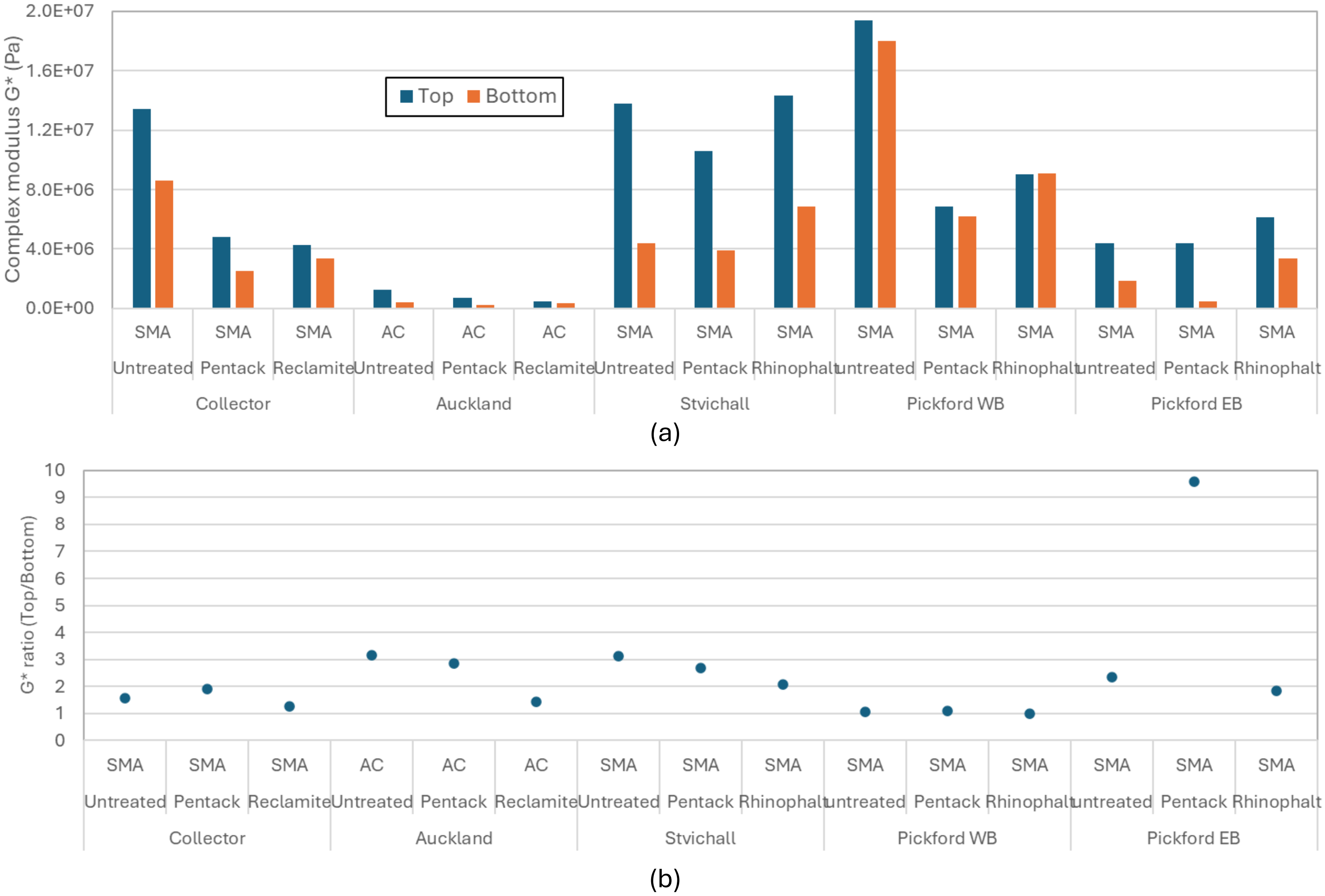


Figure 16. (a) Complex modulus (G) of binders before and after treatments, (b) G* ratio (top/bottom) at 1 Hz frequency.*

Table 4. Complex modulus values of treated and untreated binders at 1Hz frequency.

Road	Treatment	Surfacing type	G* top (1Hz, Pa)	G* bottom (1Hz, Pa)	G* top/bottom
Collector	Untreated	SMA	1.34E+07	8.58E+06	1.56
	PenTack	SMA	4.81E+06	2.53E+06	1.9
	Reclamite	SMA	4.25E+06	3.38E+06	1.26
Auckland	Untreated	HRA	1.27E+06	4.03E+05	3.15
	PenTack	HRA	7.21E+05	2.52E+05	2.86
	Reclamite	HRA	4.59E+05	3.22E+05	1.43
Stvichall	Untreated	SMA	1.38E+07	4.39E+06	3.14
	PenTack	SMA	1.06E+07	3.93E+06	2.7
	Rhinophalt	SMA	1.43E+07	6.87E+06	2.08
Pickford WB	Untreated	SMA	1.94E+07	1.80E+07	1.08
	PenTack	SMA	6.86E+06	6.19E+06	1.11
	Rhinophalt	SMA	9.00E+06	9.09E+06	0.99
Pickford EB	Untreated	SMA	4.40E+06	1.88E+06	2.34
	PenTack	SMA	4.40E+06	4.60E+05	9.57
	Rhinophalt	SMA	6.16E+06	3.36E+06	1.83

To analyse the suitability of the surface treatments, samples were categorized based on the temperature (T) and complex modulus (G*) at which the phase angle reaches 45° when tested 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 5. Table 6 presents the categories of surface treated binders recovered from the top and bottom regions of samples.

The PenTack and Reclamite treatments demonstrated a strong ability to shift the binder classifications (e.g., Category C → B → A) by significantly lowering the crossover temperature, a change primarily attributed to the lighter components in the maltene and emulsion-based rejuvenators. Conversely, Rhinophalt often maintained the existing category and produced a more subtle shift; for instance, at the Pickford WB site, the top layer remained in Category C even after treatment. These results aligned with earlier observations that Rhinophalt focused on stabilizing the binder structure rather than aggressively "softening" the material through the addition of oily components.

Table 5. 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.

Table 6. Categories of different surface treatments

Road	Treatment type	Surfacing type	Bottom Binder T (°C)	Bottom Binder G*	Bottom Binder Category	Top Binder T (°C)	Top Binder G*	Top Binder Category
Collector	Untreated	SMA	29.30	5.03	C	23.57	7.10	C
Collector	PenTack	SMA	21.60	5.34	C	16.69	6.42	B
Collector	Reclamite	SMA	19.86	5.97	B	14.69	10.48	A
Auckland	Untreated	HRA	8.89	14.07	A	<5C	>10MPa at 5C	A
Aukland	PenTack	HRA	6.60	13.29	A	<5C	8MPa at 5C	A
Aukland	Reclamite	HRA	<5C	>10MPa at 5C	A	<5C	9.2MPa at 5C	A
Pickford EB	Untreated	SMA	16.16	10.36	A	9.72	12.50	A
Pickford EB	PenTack	SMA	15.05	12.13	A	<5C	7.6MPa at 5C	A
Pickford EB	Rhinophalt	SMA	17.48	12.17	A	11.97	16.65	A
Pickford WB	Untreated	SMA	23.67	15.67	A	23.33	15.50	C
Pickford WB	PenTack	SMA	18.77	10.76	A	15.87	15.33	A
Pickford WB	Rhinophalt	SMA	19.77	11.31	A	20.07	11.71	C
Stvichall	Untreated	SMA	26.54	7.21	C	16.06	10.47	A
Stivichall	PenTack	SMA	25.86	6.24	C	15.18	10.49	A
Stivichall	Rhinophalt	SMA	28.91	5.78	C	21.59	7.39	C

4.5 SARA Chemical Characterization

The chemical composition of asphalt binders undergoes significant transformation during aging, typically characterized by the oxidation of light maltene fractions into heavier, polar asphaltenes. To evaluate how PenTack, Reclamite, and Rhinophalt restore this chemical balance across various field sites (Collector, Pickford WB, Auckland, Pickford EB, and Stvichall), SARA analysis was carried out.

The primary mechanism observed across all treated samples was the replenishment of the maltene phase. In the Collector and Pickford WB sites, the application of PenTack and Reclamite led to a notable increase in the Saturates fraction (Figure 17 & Figure 18). This suggests that these additives effectively "soften" the aged binder by reintroducing light oily components that had been lost to oxidation. While aging typically increases the Asphaltene content, rejuvenation consistently lowered the relative percentage of these brittle components, shifting the binder toward a more flexible state. Unlike the PenTack and Reclamite, Rhinophalt exhibited a distinct chemical behaviour. The data indicates that Rhinophalt did not significantly influence the Saturates content; instead, it primarily increased the Aromatic content. This approach balances the binder chemistry rather than the simple softening effect caused by excessive oils.

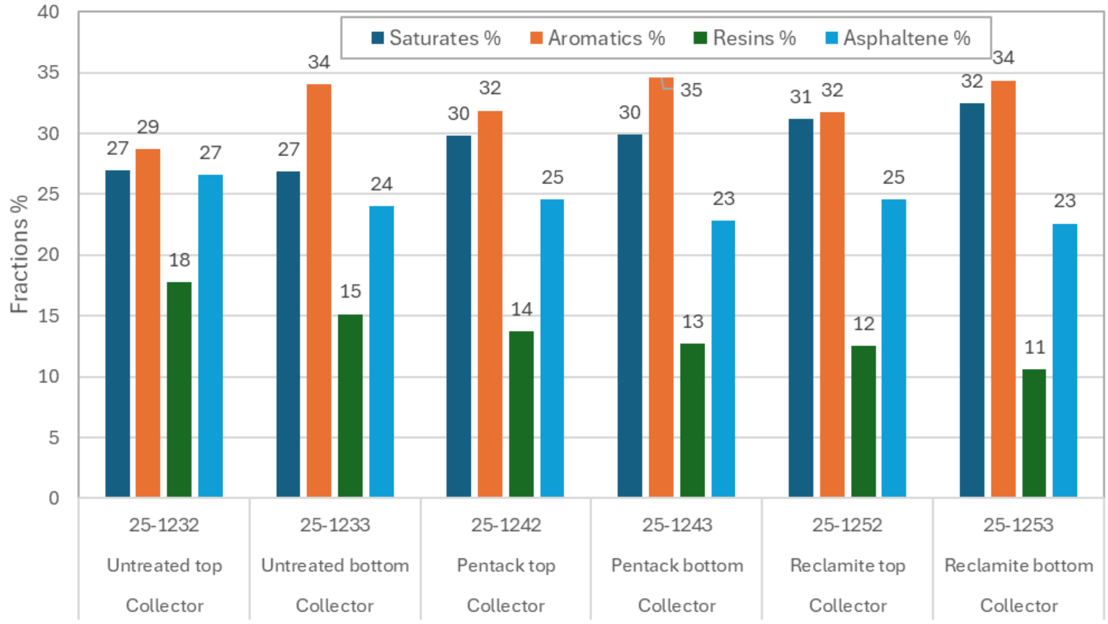


Figure 17. SARA fractions of recovered binders from Collector Road

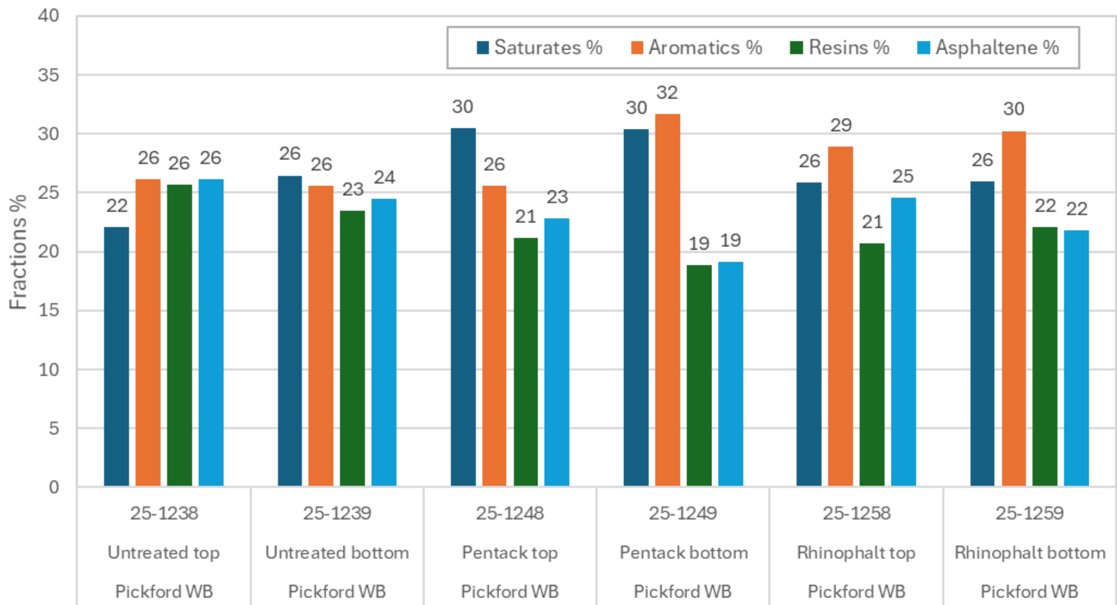


Figure 18. SARA fractions of recovered binders from Pickford WB Road

A consistent trend observed across all rejuvenators/preservatives and sites was the difference between the surface and the underlying binder (Figure 19, Figure 20, Figure 21). For all treatments, the bottom layers showed a higher Aromatic content than the top layers (Figure 17 & Figure 18). In untreated binders, this is driven by environmental exposure; the top layer's proximity to UV radiation and air accelerates the oxidative conversion of aromatics into brittle asphaltenes. In treated binders, this distribution reflects the penetration dynamics of the rejuvenators, as lighter, low-viscosity fractions such as saturates and aromatics penetrate the asphalt depth at a faster rate.

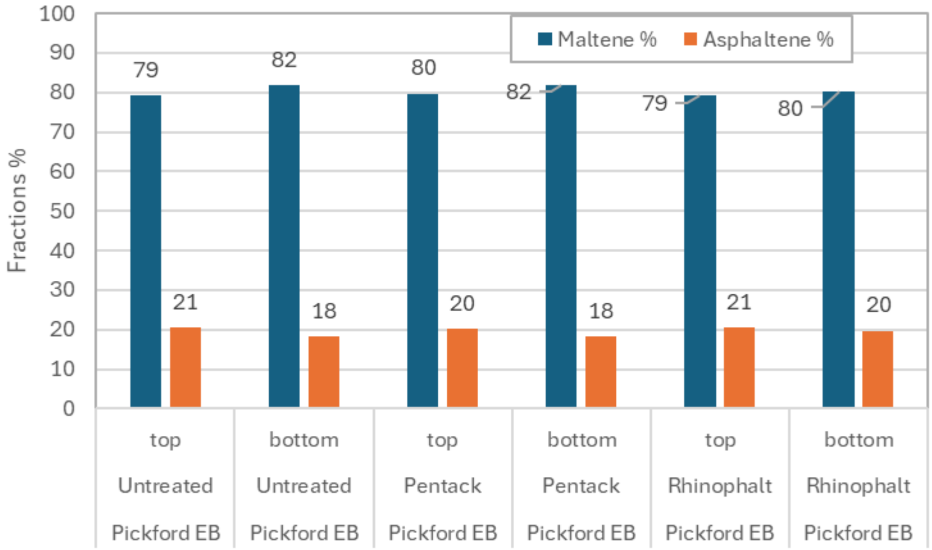


Figure 19. Asphaltene & maltene fractions of recovered binders from Pickford EB Road

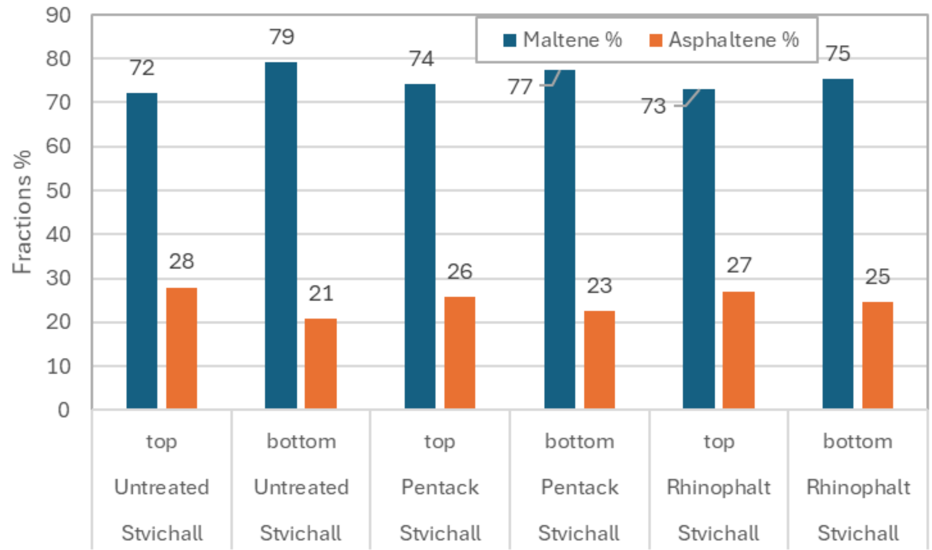


Figure 20. Asphaltene & maltene fractions of recovered binders from Stvichall EB Road

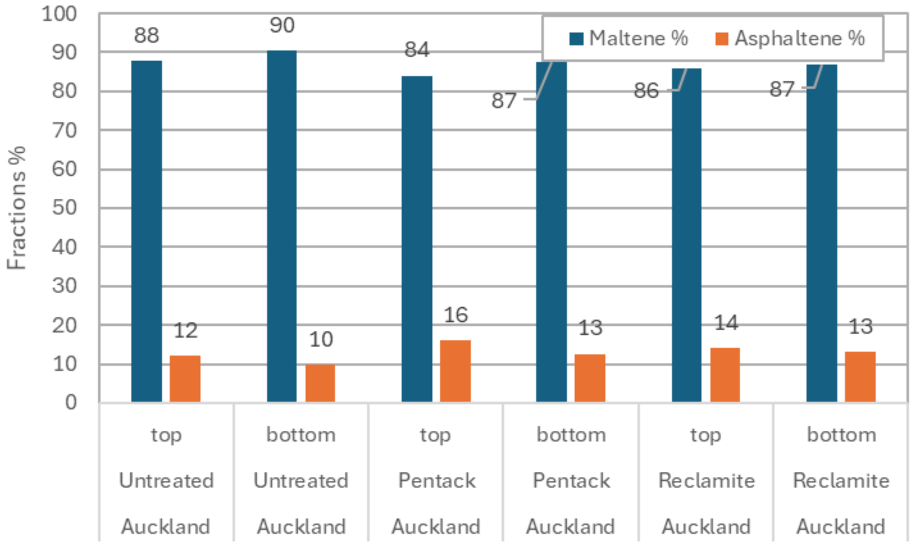


Figure 21. Asphaltene & maltene fractions of recovered binders from Auckland Road

To understand the balanced chemical composition, the Gaestel Index (I_C) was calculated. The index represents the ratio of Saturates and Asphaltenes to Aromatics and Resins. A higher I_C is characteristic of a 'Gel-type' binder, whereas a lower I_C represents a 'Sol-type' binder with better-dispersed asphaltenes. While the untreated and Rhinophalt samples generally showed lower I_C values, the PenTack and Reclamite increased the I_C values. This trend is primarily driven by the massive influx of Saturates in PenTack and Reclamite samples. Conversely, Rhinophalt primarily modified the aromatic content rather than the saturates, resulting in a more chemically balanced and stable composition compared to the saturate-heavy rejuvenators.

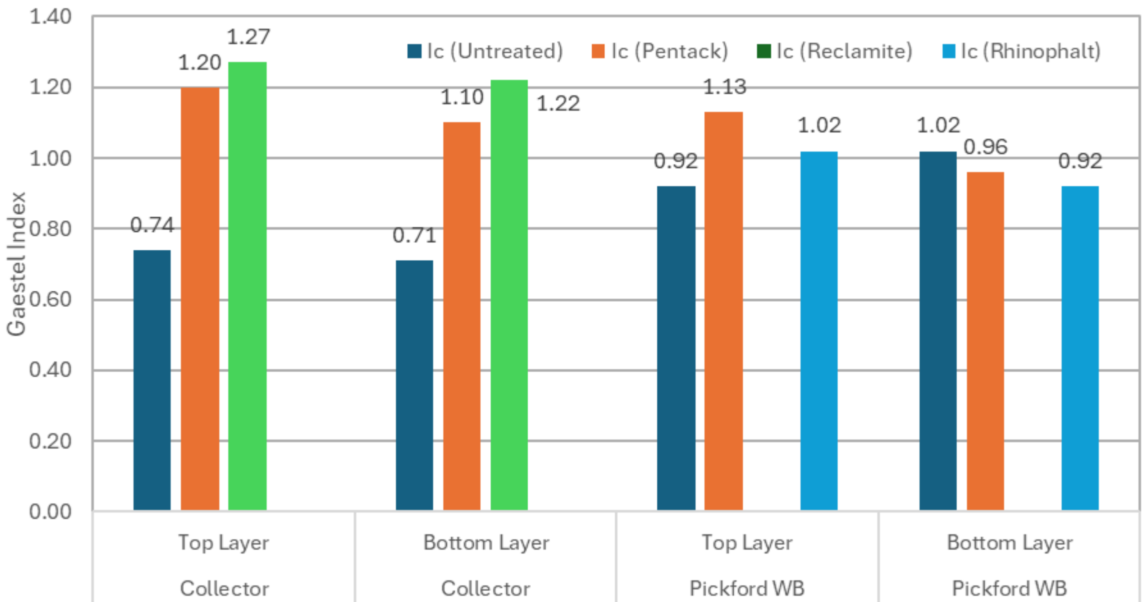


Figure 22. Gaestel Index values of different surface treated binders

5 Conclusions

The experimental results highlighted the influence of three rejuvenator/preservative surface treatments (PenTack, Reclamite, Rhinophalt) on the density, stiffness and water permeability of asphalt mixtures, and the rheological and SARA properties of the recovered binders from the top and bottom layers. The following conclusions can be drawn:

- **Density:** PenTack treated samples exhibited the highest density, followed by Reclamite and Rhinophalt samples.
- **Asphalt Mixture Stiffness:** All three surface treatments were most effective at reducing stiffness within the SMA sections. While Pentack and Reclamite achieved reductions of approximately 16-17% in Collector Road, Rhinophalt demonstrated a similar percentage reduction in the Pickford WB and Stivichall sections.
- **Water uptake:** All surface treatments successfully reduced water uptake compared to untreated samples, with Pentack emerging as the most effective. This superior performance is consistent with the increased densities observed in the Pentack samples, where improved rejuvenator penetration into the void structure of the surface materials effectively minimized moisture ingress.
- **Binder Complex Modulus:** Recovered binders from top sections consistently showed higher stiffness than bottom sections. Pentack exhibited a more pronounced reduction in binder stiffness within the lower sections, indicating the faster penetration dynamics of lighter fractions, whereas Rhinophalt demonstrated a relatively uniform stiffness throughout the entire depth.
- **Rheological Classification:** Based on the crossover temperature and complex modulus at a phase angle of 45°, Pentack and Reclamite demonstrated a strong capacity to shift binders from a brittle Category C toward a more flexible Category A or B. Rhinophalt produced more subtle shifts, often maintaining the existing category, which aligns with its role as a stabilizer rather than an aggressive softening agent.
- **Chemical stability:** Rejuvenation successfully replenished the maltene phase, but through distinct mechanisms. Pentack and Reclamite acted primarily as softening agents by significantly increasing the saturate fraction, which led to higher Gaestel Index (Ic) values. Rhinophalt, as a preservative, acted as a stabilizer by selectively enriching the aromatic content, resulting in a more chemically balanced and colloidally stable composition compared to the saturate-heavy alternatives.

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.*
3. Sakib, N., & Bhasin, A. (2019). Measuring polarity-based distributions (SARA) of bitumen using simplified chromatographic techniques. *International Journal of Pavement Engineering*, *20*(12), 1371-1384.

Appendix A Cores received from Simtec and Colas via TRL

Table A 1. Cores received from different suppliers

Sample#	Sampled	Received	Type	Container	Parent	Client Ref	Site Location	Supplier
25-402	12/03/25	12/03/25	150mm Core	N/A		Core 62 53529		West Mids Combined Auth-Simtec
25-401	12/03/25	12/03/25	150mm Core	N/A		Core 61 53528		West Mids Combined Auth-Simtec
25-400	12/03/25	12/03/25	150mm Core	N/A		Core 60 53527		West Mids Combined Auth-Simtec
25-399	12/03/25	12/03/25	150mm Core	N/A		Core 59 53526		West Mids Combined Auth-Simtec
25-398	12/03/25	12/03/25	150mm Core	N/A		Core 58 53525		West Mids Combined Auth-Simtec
25-397	12/03/25	12/03/25	150mm Core	N/A		Core 57 53524		West Mids Combined Auth-Simtec
25-396	12/03/25	12/03/25	150mm Core	N/A		Core 56 53523		West Mids Combined Auth-Simtec
25-395	12/03/25	12/03/25	150mm Core	N/A		Core 55 53522		West Mids Combined Auth-Simtec
25-394	12/03/25	12/03/25	150mm Core	N/A		Core 54 53521		West Mids Combined Auth-Simtec
25-393	12/03/25	12/03/25	150mm Core	N/A		Core 53 53520		West Mids Combined Auth-Simtec
25-392	12/03/25	12/03/25	150mm Core	N/A		Core 52 53519		West Mids Combined Auth-Simtec
25-391	12/03/25	12/03/25	150mm Core	N/A		Core 51 53518		West Mids Combined Auth-Simtec
25-390	12/03/25	12/03/25	150mm Core	N/A		Core 50 53517		West Mids Combined Auth-Simtec
25-389	12/03/25	12/03/25	150mm Core	N/A		Core 49 53516		West Mids Combined Auth-Simtec
25-388	12/03/25	12/03/25	150mm Core	N/A		Core 48 53515		West Mids Combined Auth-Simtec
25-387	12/03/25	12/03/25	150mm Core	N/A		Core 47 53514		West Mids Combined Auth-Simtec
25-386	12/03/25	12/03/25	150mm Core	N/A		Core 46 53513		West Mids Combined Auth-Simtec
25-385	12/03/25	12/03/25	150mm Core	N/A		Core 45 53512		West Mids Combined Auth-Simtec
25-384	12/03/25	12/03/25	150mm Core	N/A		Core 44 53511		West Mids Combined Auth-Simtec
25-383	12/03/25	12/03/25	150mm Core	N/A		Core 43 53510		West Mids Combined Auth-Simtec
25-382	12/03/25	12/03/25	150mm Core	N/A		Core 42 53509		West Mids Combined Auth-Simtec
25-381	12/03/25	12/03/25	150mm Core	N/A		Core 41 53508		West Mids Combined Auth-Simtec
25-380	12/03/25	12/03/25	150mm Core	N/A		Core 40 53507		West Mids Combined Auth-Simtec
25-379	12/03/25	12/03/25	150mm Core	N/A		Core 39 53506		West Mids Combined Auth-Simtec
25-378	12/03/25	12/03/25	150mm Core	N/A		Core 38 53505		West Mids Combined Auth-Simtec
25-377	12/03/25	12/03/25	150mm Core	N/A		Core 37 53504		West Mids Combined Auth-Simtec
25-376	12/03/25	12/03/25	150mm Core	N/A		Core 36 53497		West Mids Combined Auth-Simtec
25-375	12/03/25	12/03/25	150mm Core	N/A		Core 35 53496		West Mids Combined Auth-Simtec
25-374	12/03/25	12/03/25	150mm Core	N/A		Core 34 53495		West Mids Combined Auth-Simtec
25-373	12/03/25	12/03/25	150mm Core	N/A		Core 33 53494		West Mids Combined Auth-Simtec
25-372	12/03/25	12/03/25	150mm Core	N/A		Core 32 53493		West Mids Combined Auth-Simtec
25-371	12/03/25	12/03/25	150mm Core	N/A		Core 31 53492		West Mids Combined Auth-Simtec
25-370	12/03/25	12/03/25	150mm Core	N/A		Core 30 53491		West Mids Combined Auth-Simtec
25-369	12/03/25	12/03/25	150mm Core	N/A		Core 29 53490		West Mids Combined Auth-Simtec
25-368	12/03/25	12/03/25	150mm Core	N/A		Core 28 53489		West Mids Combined Auth-Simtec
25-367	12/03/25	12/03/25	150mm Core	N/A		Core 27 53488		West Mids Combined Auth-Simtec

Sample#	Sampled	Received	Type	Container	Parent	Client Ref	Site Location	Supplier
25-366	12/03/25	12/03/25	150mm Core	N/A		Core 26 53487		West Mids Combined Auth-Simtec
25-365	12/03/25	12/03/25	150mm Core	N/A		Core 25 53474		West Mids Combined Auth-Simtec
25-364	12/03/25	12/03/25	150mm Core	N/A		Core 24 53473		West Mids Combined Auth-Simtec
25-363	12/03/25	12/03/25	150mm Core	N/A		Core 23 53472		West Mids Combined Auth-Simtec
25-362	12/03/25	12/03/25	150mm Core	N/A		Core 22 53471		West Mids Combined Auth-Simtec
25-361	12/03/25	12/03/25	150mm Core	N/A		Core 21 53470		West Mids Combined Auth-Simtec
25-360	12/03/25	12/03/25	150mm Core	N/A		Core 20 54369		West Mids Combined Auth-Simtec
25-359	12/03/25	12/03/25	150mm Core	N/A		Core 19 53488		West Mids Combined Auth-Simtec
25-358	12/03/25	12/03/25	150mm Core	N/A		Core 18 53467		West Mids Combined Auth-Simtec
25-357	12/03/25	12/03/25	150mm Core	N/A		Core 17 53466		West Mids Combined Auth-Simtec
25-356	12/03/25	12/03/25	150mm Core	N/A		Core 16 53465		West Mids Combined Auth-Simtec
25-355	12/03/25	12/03/25	150mm Core	N/A		Core 15 53463		West Mids Combined Auth-Simtec
25-354	12/03/25	12/03/25	150mm Core	N/A		Core 14 53462		West Mids Combined Auth-Simtec
25-353	12/03/25	12/03/25	150mm Core	N/A		Core 13 53461		West Mids Combined Auth-Simtec
25-352	12/03/25	12/03/25	150mm Core	N/A		Core 12 53421		West Mids Combined Auth-Simtec
25-351	12/03/25	12/03/25	150mm Core	N/A		Core 11 53420		West Mids Combined Auth-Simtec
25-350	12/03/25	12/03/25	150mm Core	N/A		Core 10 53419		West Mids Combined Auth-Simtec
25-349	12/03/25	12/03/25	150mm Core	N/A		Core 9 53418		West Mids Combined Auth-Simtec
25-348	12/03/25	12/03/25	150mm Core	N/A		Core 8 53417		West Mids Combined Auth-Simtec
25-347	12/03/25	12/03/25	150mm Core	N/A		Core 7 53416		West Mids Combined Auth-Simtec
25-346	12/03/25	12/03/25	150mm Core	N/A		Core 6 53415		West Mids Combined Auth-Simtec
25-345	12/03/25	12/03/25	150mm Core	N/A		Core 5 53414		West Mids Combined Auth-Simtec
25-344	12/03/25	12/03/25	150mm Core	N/A		Core 4 53413		West Mids Combined Auth-Simtec
25-343	12/03/25	12/03/25	150mm Core	N/A		Core 3 53412		West Mids Combined Auth-Simtec
25-342	12/03/25	12/03/25	150mm Core	N/A		Core 2 53411		West Mids Combined Auth-Simtec
25-341	12/03/25	12/03/25	150mm Core	N/A		Core1 53410		West Mids Combined Auth-Simtec

Table A 2. Cores received from different suppliers

Sample#	Sampled	Received	Type	Container	Parent	Client Ref	Site Location	
25-284	03/02/25	03/02/25	150mm Core	N/A		Core 40 LMS 215042		Colas via TRL
25-283	03/02/25	03/02/25	150mm Core	N/A		Core 39 LMS 215041		Colas via TRL
25-282	03/02/25	03/02/25	150mm Core	N/A		Core 38 LMS 215040		Colas via TRL
25-281	03/02/25	03/02/25	150mm Core	N/A		Core 37 LMS 215039		Colas via TRL
25-280	03/02/25	03/02/25	150mm Core	N/A		Core 36 LMS 215038		Colas via TRL
25-279	03/02/25	03/02/25	150mm Core	N/A		Core 35 LMS 215037		Colas via TRL
25-278	03/02/25	03/02/25	150mm Core	N/A		Core 34 LMS 215036		Colas via TRL
25-277	03/02/25	03/02/25	150mm Core	N/A		Core 33 LMS 215035		Colas via TRL
25-276	03/02/25	03/02/25	150mm Core	N/A		Core 32 LMS 215034		Colas via TRL
25-275	03/02/25	03/02/25	150mm Core	N/A		Core 31 LMS 215033		Colas via TRL
25-274	03/02/25	03/02/25	150mm Core	N/A		Core 30 LMS 215031		Colas via TRL
25-273	03/02/25	03/02/25	150mm Core	N/A		Core 29 LMS 215031		Colas via TRL
25-272	03/02/25	03/02/25	150mm Core	N/A		Core 28 LMS 215030		Colas via TRL
25-271	03/02/25	03/02/25	150mm Core	N/A		Core 27 LMS 215029		Colas via TRL
25-270	03/02/25	03/02/25	150mm Core	N/A		Core 26 LMS 215028		Colas via TRL
25-269	03/02/25	03/02/25	150mm Core	N/A		Core 25 LMS 215027		Colas via TRL
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25-264	03/03/25	03/03/25	150mm Core	N/A		Core 20 LMS 215022		Colas via TRL
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25-261	03/02/25	03/02/25	150mm Core	N/A		Core 17 LMS 215019		Colas via TRL
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25-252	03/02/25	03/02/25	150mm Core	N/A		Core 8 LMS 215010		Colas via TRL
25-251	03/02/25	03/02/25	150mm Core	N/A		Core 7 LMS 215009		Colas via TRL
25-250	03/02/25	03/02/25	150mm Core	N/A		Core 6 LMS 215008		Colas via TRL
25-249	03/03/25	03/02/25	150mm Core	N/A		Core 5 LMS 215007		Colas via TRL

Sample#	Sampled	Received	Type	Container	Parent	Client Ref	Site Location	
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25-247	03/02/25	03/02/25	150mm Core	N/A		Core 3 LMS 215005		Colas via TRL
25-246	03/02/25	03/02/25	150mm Core	N/A		Core 2 LMS 215004		Colas via TRL
25-245	03/02/25	03/02/25	150mm Core	N/A		Core 1 LMS 215003		Colas via TRL

CORE SAMPLE REPORT - DETERMINATION OF THE THICKNESS OF A BITUMINOUS PAVEMENT (BS EN 12697-36:2003-WITHDRAWN)

UKAS TESTING 10108

SIMTEC CONSTRUCTION MATERIALS TESTING
Unit 116, The Burrows, East Goscote Ind Est,
East Goscote, Leicestershire, LE7 3XD
t: 0116 3196100 e: info@simtec-mt.co.uk

Job Ref No.: SMTi23677
Client Name:- West Midlands Combined Authority
Client Address:- 16 Summer Lane, Birmingham, West Midlands, B19 3SD
Client Ref:- 4004925
Ref No/Scheme:- Collector Road Solihull
Sample Reference No:- Core 31
GPS Ref:- N/A
Sample Certificate Received: Yes
Date of Receipt of Sample: 22/01/2025

Certificate No.:- CERT016-SMTi23677-CL1
Date of Report:- 03/02/2025
Page:- 7 of 12
Ref, Location, Direction, Wheel Path:- 53590, Collector Road
General Pavement Condition:- N/A
Sampled in Accordance with: BS EN 12697-27:2017 (laid and compacted material by coring)

Layer	Depth from (mm)	Depth to (mm)	Thickness (mm)	Material Description	Max Agg Size (mm)	Aggregate Type	PAK Spray	Bond Condition	Layer Comment
1	0	42	42	Stone Mastic Asphalt	14	Granite	-	OK	OK
2	42	57	15	Hot Rolled Asphalt	14	Granite	-	OK	OK
3	57	171	114	Asphalt Concrete	32	Granite	-	-	OK

Date Cored:- 22/01/2025
Time Core:- 13:48
Cored By:- D. Cope
Core Diameter (mm):- 150

Date Logged:- 29/01/2025
Logged By:- J. Page
Coring Carried Out By Simtec

Approved Signatory: (X) Lee Harbottle - Laboratory Operations Manager
( ) Rob McGoff - Laboratory Supervisor

Signed:

For and on behalf on Simtec Materials Testing Ltd

Registered in England and Wales
Registration No. 6401491
Reg Office; 63 Fosse Way, Syston, Leicestershire, LE7 1NF

Where a sampling certificate has been received and includes a diagram, sketch or photos, this is available upon request.
If not sampled by Simtec Materials Testing results apply to sample as received from client.
Results relate only to the items tested.
Opinions and interpretations are outside the scope of UKAS/ISO 17025.
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Checked	

Core No.	Core 31

END OF REPORT
CERT016 - Core Log Sample - - Copy

Figure A 1. Core 31 at Collector road from Simtec

CORE SAMPLE REPORT - DETERMINATION OF THE THICKNESS OF A BITUMINOUS PAVEMENT (BS EN 12697-36:2003-WITHDRAWN)

UKAS TESTING 10108

SIMTEC CONSTRUCTION MATERIALS TESTING
Unit 116, The Burrows, East Goscote Ind Est,
East Goscote, Leicestershire, LE7 3XD
t: 0116 3196100 e: info@simtec-mt.co.uk

Job Ref No.: SMTi23679
Client Name:- West Midlands Combined Authority
Client Address:- 16 Summer Lane, Birmingham, West Midlands, B19 3SD
Client Ref:- 4004927
Ref No/Scheme:- Close Stivichill Bypass
Sample Reference No:- Core 49
GPS Ref:- N/A
Sample Certificate Received: Yes
Date of Receipt of Sample: 22/01/2025

Certificate No.:- CERT016-SMTi23679-CL1
Date of Report:- 04/02/2025
Page:- 1 of 14

Ref, Location, Direction, Wheel Path:- Stivichall Bypass
General Pavement Condition:- N/A
Sampled in Accordance with: BS EN 12697-27:2017 (laid and compacted material by coring)

Layer	Depth from (mm)	Depth to (mm)	Thickness (mm)	Material Description	Max Agg Size (mm)	Aggregate Type	PAK Spray	Bond Condition	Layer Comment
1	0	45	45	Hot Rolled Asphalt (PCC 20mm on top)	14	Granite	N/A	OK	OK
2	45	108	63	Asphalt Concrete	20	Granite	N/A	OK	OK
3	108	165	57	Hot Rolled Asphalt	32	Granite	N/A	N/A	OK

Date Cored:- 22/01/2025
Time Core:- 20:05
Cored By:- D. Cope
Core Diameter (mm):- 143

Date Logged:- 30/01/2025
Logged By:- H. Chariwala
Coring Carried Out By Simtec

Approved Signatory: (X) Lee Harbottle - Laboratory Operations Manager
( ) Rob McGoff - Laboratory Supervisor

Signed:

For and on behalf on Simtec Materials Testing Ltd

Registered in England and Wales
Registration No. 6401491
Reg Office; 63 Fosse Way, Syston, Leicestershire, LE7 1NF

Where a sampling certificate has been received and includes a diagram, sketch or photos, this is available upon request.
If not sampled by Simtec Materials Testing results apply to sample as received from client.
Results relate only to the items tested.
Opinions and interpretations are outside the scope of UKAS/ISO 17025.
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Checked	

Core No.	Core 49

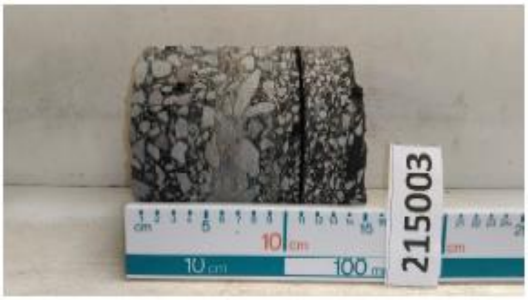
END OF REPORT
CERT016 - Core Log Sample - - Copy

Figure A 2. Core 49 at Stivichill Bypass from Simtec

THE FUTURE OF TRANSPORT

Core Log Form

Core Log: 1 - 215003



Layers					Aggregate		General Remarks			PAK Test
No.	**Top (mm)**	**Btm (mm)**	**Thickness (mm)**	**Material type**	**Max size (mm)**	**Type**	**Condition**	**Bond**	**Voids (Yes/No)**	**+ve /-ve**
1	0	38	38	TS	14	GS	Sound	Intact	Yes	Negative
2	38	110	72	DBM	28	LST	Sound	Debonded	No	Negative
3	110	143	33	DBM	6	LST	Sound	Intact	Yes	Negative
4	143	156	13	HRA	10	LST	Sound	N/A	No	Negative

Cored at:	**Subbase type:** Cbm	**Site remarks:**	
Time of coring: 09:49	**Hole depth:** 155		
Abbreviations: SD=Surface Dressing; SMA= Stone Mastic Asphalt; TS=Thin Surfacing; HRA=Hot Rolled Asphalt; DBM =Dense Bituminous Macadam; HBM=Hydraulically Bound Material; PQC=Pavement Quality Concrete; GS=Gritstone; GNT=Granite; LST=Limestone; GVL=Gravel;		**Core Ref:**	1
		Core Diameter (mm):	150

Client:	Colas		**TRL LMS Ref:**	215003
Project:	Colas-Solihull Coring		**Project Code:**	11226356
	Direction: Eastbound		**Coring Date:**	27/08/2024
Section:	**Lane:**	**Offset:** 2,84	**Logged By:**	Mark Charlton
Section Chainage: m	**Lat:** 0	**Long:** 0	**Checked By:**	John Prime

Core Log: 1 - 215003

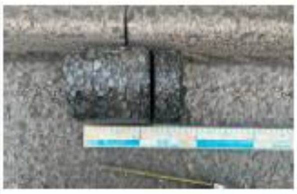
Picture of core on site	Picture of core location
	
Picture of core hole	**Picture of reinstatement**
	

Figure A 3. Core 1 from Colas and TRL

TRL THE FUTURE OF TRANSPORT

Core Log Form

Core Log: 20 - 215022

Layers					Aggregate		General Remarks			PAK Test
No.	**Top (mm)**	**Btm (mm)**	**Thickness (mm)**	**Material type**	**Max size (mm)**	**Type**	**Condition**	**Bond**	**Voids (Yes/No)**	**+ve /-ve**
1	0	52	52	TS	14	GS	Sound	Intact	Yes	Negative
2	52	170	118	DBM	24	LST	Sound	N/A	Yes	Negative

Cored at:	**Subbase type:** Not applicable	**Site remarks:**	
Time of coring: 09:19	**Hole depth:** 160		
Abbreviations: SD=Surface Dressing; SMA= Stone Mastic Asphalt; TS=Thin Surfacing; HRA=Hot Rolled Asphalt; DBM =Dense Bituminous Macadam; HBM=Hydraulically Bound Material; PQC=Pavement Quality Concrete; GS=Gritstone; GNT=Granite; LST=Limestone; GVL=Gravel;		**Core Ref:**	20
		Core Diameter (mm):	150

Client:	Colas		**TRL LMS Ref:**	215022
Project:	Colas-Solihull Coring		**Project Code:**	11226356
	Direction: Southbound		**Coring Date:**	28/08/2024
Section:	**Lane:**	**Offset:** ,243	**Logged By:**	Mark Charlton
Section Chainage: Collector roadm	**Lat:** 0	**Long:** 0	**Checked By:**	John Prime

Core Log: 20 - 215022

Picture of core on site	Picture of core location
	
Picture of core hole	**Picture of reinstatement**
	

Figure A 4. Core 20 from Colas and TRL

Appendix B NTEC sample reference numbers for the cores received from different roads

Table B 1. Cores received from different roads and their mixture types

Collector Road							
Untreated		PenTack		Reclamite		Rhinophalt	
15	25-259	25	25-365	31	25-371		
16	25-260	26	25-366	32	25-372		
17	25-261	27	25-367	33	25-373		
18	25-262	28	25-368	34	25-374		
19	25-263	29	25-369	35	25-375		
20	25-264	30	25-370	36	25-376		
21	25-265						
Aukland							
Untreated		PenTack		Reclamite		Rhinophalt	
22	25-266	43	25-383	37	25-377		
23	25-267	44	25-384	38	25-378		
24	25-268	45	25-385	39	25-379		
25	25-269	46	25-386	40	25-380		
26	25-270	47	25-387	41	25-381		
27	25-271	48	25-388	42	25-382		
28	25-272						
29	25-273						
Stivichall							
Untreated		PenTack		Reclamite		Rhinophalt	
30	25-274	49	25-389			57	25-397
31	25-275	50	25-390			58	25-398
32	25-276	51	25-391			59	25-399
33	25-277	52	25-392			60	25-400
34	25-278	53	25-393			61	25-401
35	25-279	54	25-394			62	25-402
36	25-280	55	25-395				
37	25-281	56	25-396				
Pickford WB							
8	25-252	1	25-341			7	25-347
9	25-253	2	25-342			8	25-348
10	25-254	3	25-343			9	25-349
11	25-255	4	25-344			10	25-350
12	25-256	5	25-345			11	25-351
13	25-257	6	25-346			12	25-352
14	25-258						
Pickford EB							
1	25-245	13	25-353			19	25-359
2	25-246	14	25-354			20	25-360
3	25-247	15	25-355			21	25-361
4	25-248	16	25-356			22	25-362
5	25-249	17	25-357			23	25-363
6	25-250	18	25-358			24	25-364
7	25-251						

Core descriptions

- Thin surfacing (SMA)
- SMA
- Asphalt concrete
- HRA

Appendix C Density & Stiffness Measurements

Table C 1. Data sheet for Density and Stiffness measurements

Sample Number	Diameter/mm	Thickness/mm	Mass/g	Density Mg/m3 (Dims)	Stiffness/MPa
25-245	148.7	38.6	1554.7	2.319	4886
25-246	149.1	39.6	1574.9	2.278	4831
25-247	149.0	39.0	1637.0	2.407	5151
25-248	149.1	41.3	1625.3	2.254	5463
25-249	148.9	42.1	1650.3	2.251	5115
25-250	149.2	39.0	1555.8	2.282	4524
25-259	149.1	42.4	1749.2	2.363	5699
25-260	149.1	42.2	1613.7	2.190	3437
25-261	149.1	40.3	1630.6	2.317	5110
25-262	149.2	41.4	1638.9	2.264	4767
25-263	149.2	40.4	1633.9	2.313	4738
25-264	149.2	39.6	1622.6	2.344	4952
25-353	143.2	40.3	1530.0	2.357	4191
25-354	142.6	41.3	1526.7	2.315	3495
25-355	143.0	41.8	1540.1	2.294	4650
25-356	142.6	39.1	1439.3	2.305	3422
25-357	143.1	40.5	1483.0	2.277	4938
25-358	142.8	41.7	1558.1	2.333	3706
25-359	143.1	40.1	1471.7	2.282	4329
25-360	142.9	42.7	1563.8	2.283	4011
25-361	143.2	41.9	1547.1	2.293	4053
25-362	142.7	42.7	1527.7	2.237	4156
25-363	143.1	41.7	1562.2	2.329	5570
25-364	142.8	41.8	1559.9	2.330	3776
25-371	143.2	42.8	1664.5	2.415	3980
25-372	143.2	41.6	1551.9	2.316	4064
25-373	143.1	42.5	1618.7	2.368	3873
25-374	143.3	42.2	1631.3	2.397	3444
25-375	143.1	41.9	1524.9	2.263	4603
25-376	143.0	41.7	1555.9	2.323	4270

Sample Number	Diameter/mm	Thickness/mm	Mass/g	Density Mg/m3 (Dims)	Stiffness/MPa
25-251	149.2	34.9	1415.0	2.319	3677
25-252	N/A	N/A	N/A	N/A	N/A
25-253	148.7	37.9	1484.5	2.255	6004
25-254	148.7	43.0	1612.3	2.159	5525
25-255	149.0	42.2	1620.7	2.203	6751
25-256	149.1	40.0	1546.2	2.214	7031
25-257	149.2	41.0	1622.8	2.264	5973
25-258	149.7	40.2	1637.6	2.314	5719
25-265	148.9	38.5	1509.6	2.252	5106
25-266	149.3	39.8	1707.7	2.451	1420
25-267	149.3	38.8	1651.2	2.431	1500
25-268	149.2	40.8	1706.8	2.393	2222
25-269	149.2	39.4	1649.5	2.395	2780
25-270	149.2	40.5	1717.8	2.426	2136
25-271	149.2	39.8	1694.6	2.435	2419
25-272	149.4	39.3	1677.2	2.434	1431
25-273	149.3	38.2	1627.5	2.434	1652
25-274	149.1	41.9	1550.0	2.119	6029
25-275	149.3	41.2	1598.5	2.216	5608
25-276	149.3	40.7	1655.7	2.324	4380
25-277	149.0	41.3	1513.7	2.102	4787
25-278	148.5	41.9	1639.2	2.259	4111
25-279	149.0	40.5	1580.8	2.239	4739
25-280	149.3	40.7	1634.4	2.294	3899
25-281	149.3	40.6	1638.8	2.306	3545
25-282	149.4	40.1	1539.3	2.190	5355
25-283	149.3	41.8	1664.6	2.275	3070
25-284	149.4	40.5	1619.3	2.281	4534
25-341	143.0	41.2	1513.3	2.287	4566
25-342	142.6	42.9	1598.4	2.333	4634
25-343	142.9	41.2	1530.3	2.316	3002
25-344	142.6	41.2	1485.6	2.258	5245
25-345	143.1	42.0	1597.7	2.365	4140
25-346	142.7	42.1	1551.6	2.304	5064
25-347	142.7	42.3	1509.5	2.231	5507
25-348	142.7	42.0	1532.0	2.281	5197
25-349	143.1	42.1	1545.8	2.283	4857
25-350	142.6	40.0	1457.9	2.282	5583
25-351	143.0	42.5	1541.6	2.259	5015
25-352	142.7	41.0	1521.4	2.320	5096
25-365	143.2	42.3	1643.0	2.412	4071
25-366	143.1	41.6	1625.6	2.430	3969
25-367	143.1	41.9	1588.0	2.356	3942
25-368	143.0	42.2	1568.0	2.314	3650
25-369	143.1	42.1	1558.6	2.302	4090
25-370	143.0	41.6	1604.2	2.401	3925

Sample Number	Diameter/mm	Thickness/mm	Mass/g	Density Mg/m3 (Dims)	Stiffness/MPa
25-377	142.9	38.9	1526.3	2.446	1546
25-378	142.9	39.0	1541.2	2.464	1486
25-379	142.8	41.2	1594.1	2.416	2512
25-380	142.7	40.4	1576.4	2.440	2044
25-381	142.8	40.8	1596.6	2.443	1833
25-382	142.8	41.4	1597.6	2.409	2941
25-383	142.8	38.5	1479.8	2.400	1705
25-384	142.9	40.6	1592.4	2.446	2081
25-385	142.9	39.4	1526.5	2.416	1856
25-386	142.9	41.3	1615.8	2.439	3205
25-387	143.0	40.4	1581.9	2.438	1341
25-388	142.4	41.1	1584.4	2.421	1525
25-389	143.1	43.0	1488.7	2.153	5489
25-390	142.3	43.5	1608.5	2.325	5243
25-391	143.1	42.4	1596.4	2.341	3680
25-392	142.4	41.8	1588.7	2.386	3980
25-393	143.3	41.0	1552.3	2.348	4532
25-394	N/A	N/A	N/A	N/A	N/A
25-395	143.1	43.9	1537.5	2.178	3980
25-396	142.3	41.9	1465.7	2.200	4722
25-397	143.0	40.6	1432.6	2.197	4743
25-398	142.4	40.5	1422.4	2.205	4732
25-399	143.0	41.8	1511.6	2.252	2728
25-400	142.5	42.3	1442.4	2.138	2616
25-401	143.0	42.7	1498.7	2.185	2449
25-402	142.5	40.0	1423.7	2.232	3251

Table C 2. NTEC test report for density measurement of 25-253 sample

NOTTINGHAM TRANSPORTATION ENGINEERING CENTRE

DETERMINATION OF BULK DENSITY BY DIMENSIONS AND AIR VOIDS

BSEN 12697-6:2020 & BSEN12697-8:2018 **WS/PT0131/ISSUE 10**

Job Number	13130
Sample Number	**25-253**
Test Order No.	15931
Date Result Required	No date given
Residue to be retained (Y/N)	Yes
Storage Location	C/s

EQUIPMENT DETAILS						
	Equipment No.				Equipment No.	
Straight Edge	E		Balance		E4251	
Timer	E		Calipers		E2621	
THICKNESS (CORES or SLAB)						
Thickness of Specimen (mm) To nearest 0.1mm	35.2	37.1	40.0	39.3		
(Min 20mm or 2x nominal stone size whichever is the greater)				Mean Thickness (mm) **(h)**	37.9	
DIAMETER (CORES)						
Diameter of specimen (mm) Nearest 0.1mm	Top 148.9	Top 148.9	Middle 148.7	Middle 148.8	Bottom 148.3	Bottom 148.8
				Mean Diameter mm **(d)**	148.7	
Specimen cleaned by brushing or washing			~~Yes~~/ No (not necessary)			
	Initial	1st	2nd	3rd		
Date/Time	13:53	15:24				
Mass of specimen (g)	1484.5	1484.5				
Specimen left at ambient for 1hr (tick)	✓					
Change in mass (%)	N/A	0				

DIMENSIONS (SLABS)									
Height of slab (0.1mm) H									Mean =
Length of Slab (nearest 0.5mm) **L**	mm	mm	mm	Mean =					
Width of Slab (nearest 0.1mm) **W**	mm	mm	mm	Mean =					

Density by Measurement	
Mass of specimen in air (g) **m1**	1484.5
$\rho_{bdim} = \frac{m1}{(\pi/4) \times h \times d^2} \times 10^3$ (Cylindrical)	2.255 Mg/m³
$\rho_{bdim} = \frac{m1}{H \times L \times W} \times 10^3$ (Rectangular)	Mg/m³

CALCULATION OF AIR VOIDS (If applicable)		
Bulk Density by Dimensions	ρ_{bdim}	2.255 **Mg/m³**
Maximum Density of Bituminous Mixture (Calculated / Measured)	**M**	**Mg/m³**
Air Void content of compacted mixtures **(TO ONE DECIMAL POINT)**	$\frac{100(M-\rho_{bdim})}{M}$	%

	Dimensions By	Calculation By	Checked By	Data Entry
Date	15/05/25	15/05/25	~~06/05~~ 06/06/25	21/05/25
Signed	CB	CB	RB	CB

Page 3 of 65

Figure C 1. IT-CY stiffness measurement device

Table C 3. NTEC test report for density measurement of 25-253 sample

NOTTINGHAM TRANSPORTATION ENGINEERING CENTRE

DETERMINATION OF THE STIFFNESS OF BITUMINOUS MIXTURES BY APPLYING INDIRECT TENSION TO CYLINDRICAL SPECIMENS (IT-CY)

BSEN12697-26:2004 ANNEX C **WS/PT0030(BSEN)/ISSUE 6**

Job Number	13130
Sample Number	**25-253**
Test Order No.	15932
Date Result Required	No date given
Residue to be retained (Y/N)	Yes
Storage Location	C/s

EQUIPMENT DETAILS			
	Equipment No.		Equipment No.
Cold Room	**E1011**	NAT/ NU-14 Load Frame	E 2199
Vernier Callipers	E 2691	Conditioning Cabinet	E 2446
Sub frame and cradle	E 0151	Upper Loading Platen	E 1449 / 10 RB
Digital Thermometer	E 1651	Lower Loading Platen	E 1449 / 252
1st Dummy	E 4240	2nd Dummy	E 1650 / 2574 RB

DIMENSIONS (nearest 0.1mm)							
Nominal Ø	80* / 100* / 120* / 150* / 200*		Specimen Homogeneous			YES* / NO*	UO
	1	2	3	4			Mean (0.1mm)
Thickness (mm) 30-75mm		P/T					37.9
	1	2	3	4	5	6	
Diameter (mm)			P/T				148.7
Test Temperature Required (°C) delete as appropriate	+2.0* / +10.0* / +20.0* / Other:						

STORAGE CONDITIONS (Placed flat face down on a horizontal surface & NOT stacked)						
Date/ Time	Received	Storage ≤ 25°C-IN	Storage ≤ 5°C-IN	Conditioning Cabinet-IN	Point of test-IN	Testing Completed
1st				25/06/25 12:20	26/06/25 14:31	26/06/25 14:39
2nd	N/A	N/A	N/A	N/A	N/A	

TEST TEMPERATURES	1st Dummy			2nd Dummy		
	Outside	Centre	Mean	Outside	Centre	Mean
Recorded Cond (°C)	20.5	20.5			N/A	
Actual Cond (°C)	20.3	20.2	20.3		N/A	
Point of Test (°C)	N/A	N/A	N/A	20.1	19.9	20.0

STIFFNESS MEASUREMENT	1st Ø	2nd Ø
Poissons ratio set at 0.35 (TICK)	✓	✓
10 Conditioning pulses applied (TICK)	✓	✓
Mean Vertical Load (kN)	2.327	2.333
Mean Load Area factor (**0.50-0.70**)	0.64	0.64
Mean Horizontal Deformation (μm)**150 (7±2), 100 (5±2)**	6.473	6.540
Mean Risetime (ms) **Target = 124±4ms**	124	126
k=0.6: Adjusted Stiffness Modulus (MPa)	6027	5981
% Diff' between 1st & 2nd Ø (within +10% or -20% of 1ST Ø) =((2nd Ø-1st Ø)/ 1st Ø)*100	-0.8	
Mean Adjusted Stiffness Modulus (MPa) k=0.6	6004	
Printout of Tests **STAPLED** to worksheet (TICK)	✓	

	Dimensions By	**Tested By**	**Checked By**	**Data Entry**
Date	P/T	26/06/25	10/7/25	02/07/25
Signed		RB		RB

Appendix D Water uptake measurements

	
(a) Wrapped cores	(b) Measuring weights
	
(c) Water infiltration chamber	(d) Vacuum saturation

Figure D 1. Water uptake measurements in asphalt cores

Table D 1. Data sheet for water uptake measurements

Sample Number	Mass Dry/g	Mass Dry+Foil/g	Foil Mass/g	Mass After Saturation/g	Mass of Water Uptake/g
25-259	1749.5	1752.1	2.6	1756.2	4.1
25-260	1614.0	1616.5	2.5	1636.1	19.6
25-261	1631.4	1634.0	2.6	1641.6	7.6
25-262	1637.4	1640.1	2.7	1655.0	14.9
25-263	1634.2	1637.1	2.9	1644.3	7.2
25-264	1622.3	1625.1	2.8	1634.2	9.1
25-268	1706.2	1708.9	2.7	1710.7	1.8
25-269	1649.2	1651.8	2.6	1654.2	2.4
25-270	1717.9	1720.8	2.9	1722.7	1.9
25-271	1694.6	1697.4	2.8	1699.5	2.1
25-272	1677.4	1680.2	2.8	1681.0	0.8
25-273	1627.7	1630.4	2.7	1631.4	1.0
25-274	1549.8	1552.5	2.7	1559.6	7.1
25-275	1598.2	1600.9	2.7	1607.2	6.3
25-276	1656.1	1658.9	2.8	1663.0	4.1
25-277	1507.1	1509.8	2.7	1529.6	19.8
25-278	1638.5	1641.3	2.8	1649.9	8.6
25-279	1578.8	1581.5	2.7	1596.8	15.3
25-253	1484.0	1486.6	2.6	1495.7	9.1
25-254	1608.5	1611.1	2.6	1626.3	15.2
25-255	1617.6	1620.5	2.9	1629.1	8.6
25-256	1544.0	1546.9	2.9	1556.2	9.3
25-257	1622.4	1625.1	2.7	1629.1	4.0
25-258	1637.0	1639.7	2.7	1644.4	4.7
25-245	1557.2	1559.8	2.6	1563.9	4.1
25-246	1577.1	1579.6	2.5	1585.6	6.0
25-247	1639.3	1642.0	2.7	1647.4	5.4
25-248	1627.4	1630.1	2.7	1637.5	7.4
25-249	1651.5	1654.2	2.7	1669.5	15.3
25-250	1556.7	1559.4	2.7	1563.6	4.2
25-365	1643.7	1646.3	2.6	1648.8	2.5
25-366	1625.6	1628.5	2.9	1629.7	1.2
25-367	1586.5	1589.1	2.6	1591.5	2.4
25-368	1567.0	1569.6	2.6	1572.8	3.2
25-369	1557.0	1559.7	2.7	1561.7	2.0
25-370	1603.2	1605.9	2.7	1606.9	1.0
25-383	1480.6	1483.5	2.9	1484.8	1.3
25-384	1593.4	1596.4	3.0	1597.5	1.1
25-385	1527.1	1529.9	2.8	1531.5	1.6
25-386	1615.9	1618.5	2.6	1619.2	0.7
25-387	1582.2	1585.0	2.8	1585.6	0.6
25-388	1584.8	1587.5	2.7	1588.8	1.3

Sample Number	Mass Dry/g	Mass Dry+Foil/g	Foil Mass/g	Mass After Saturation/g	Mass of Water Uptake/g
25-389	1489.0	1492.1	3.1	1498.0	5.9
25-390	1608.8	1611.9	3.1	1614.4	2.5
25-391	1594.3	1597.4	3.1	1599.6	2.2
25-392	1558.6	1561.5	2.9	1564.7	3.2
25-393	1552.7	1555.5	2.8	1559.3	3.8
25-395	1533.4	1536.3	2.9	1544.8	8.5
25-341	1510.8	1513.6	2.8	1515.7	2.1
25-342	1596.1	1598.7	2.6	1601.9	3.2
25-343	1528.1	1530.9	2.8	1536.3	5.4
25-344	1482.0	1484.7	2.7	1486.9	2.2
25-345	1597.2	1599.9	2.7	1600.7	0.8
25-346	1548.7	1551.5	2.8	1552.5	1.0
25-353	1529.9	1532.9	3.0	1533.3	0.4
25-354	1527.2	1530.0	2.8	1532.3	2.3
25-355	1539.4	1542.4	3.0	1543.2	0.8
25-356	1439.3	1442.1	2.8	1444.6	2.5
25-357	1481.3	1484.1	2.8	1485.5	1.4
25-358	1558.2	1561.1	2.9	1562.9	1.8
25-371	1664.1	1666.8	2.7	1668.9	2.1
25-372	1550.3	1552.9	2.6	1558.1	5.2
25-373	1618.1	1620.7	2.6	1624.2	3.5
25-374	1631.8	1634.4	2.6	1636.3	1.9
25-375	1521.3	1523.9	2.6	1530.7	6.8
25-376	1553.8	1556.5	2.7	1562.8	6.3
25-377	1527.2	1529.8	2.6	1530.5	0.7
25-378	1542.1	1544.6	2.5	1545.0	0.4
25-379	1594.1	1596.6	2.5	1597.7	1.1
25-380	1576.0	1578.5	2.5	1579.0	0.5
25-381	1596.1	1598.3	2.2	1599.3	1.0
25-382	1596.6	1599.5	2.9	1601.1	1.6
25-397	1434.5	1437.3	2.8	1445.2	7.9
25-398	1425.4	1428.0	2.6	1438.5	10.5
25-399	1508.0	1510.7	2.7	1518.0	7.3
25-400	1430.9	1433.8	2.9	1439.5	5.7
25-401	1495.8	1498.5	2.7	1508.6	10.1
25-402	1421.0	1423.7	2.7	1431.3	7.6
25-347	1506.9	1509.6	2.7	1512.9	3.3
25-348	1530.6	1533.2	2.6	1535.2	2.0
25-349	1545.7	1548.4	2.7	1550.0	1.6
25-350	1456.4	1459.0	2.6	1461.4	2.4
25-351	1540.3	1542.9	2.6	1545.5	2.6
25-352	1521.3	1523.9	2.6	1526.4	2.5
25-359	1471.9	1474.6	2.7	1478.1	3.5
25-360	1563.2	1565.9	2.7	1568.5	2.6
25-361	1545.9	1548.7	2.8	1551.7	3.0
25-362	1528.1	1530.9	2.8	1535.0	4.1
25-363	1560.3	1563.1	2.8	1565.4	2.3
25-364	1559.7	1562.6	2.9	1566.1	3.5

Appendix E DSR measurements

Figure E 1. DSR testing

Appendix F SARA Analysis

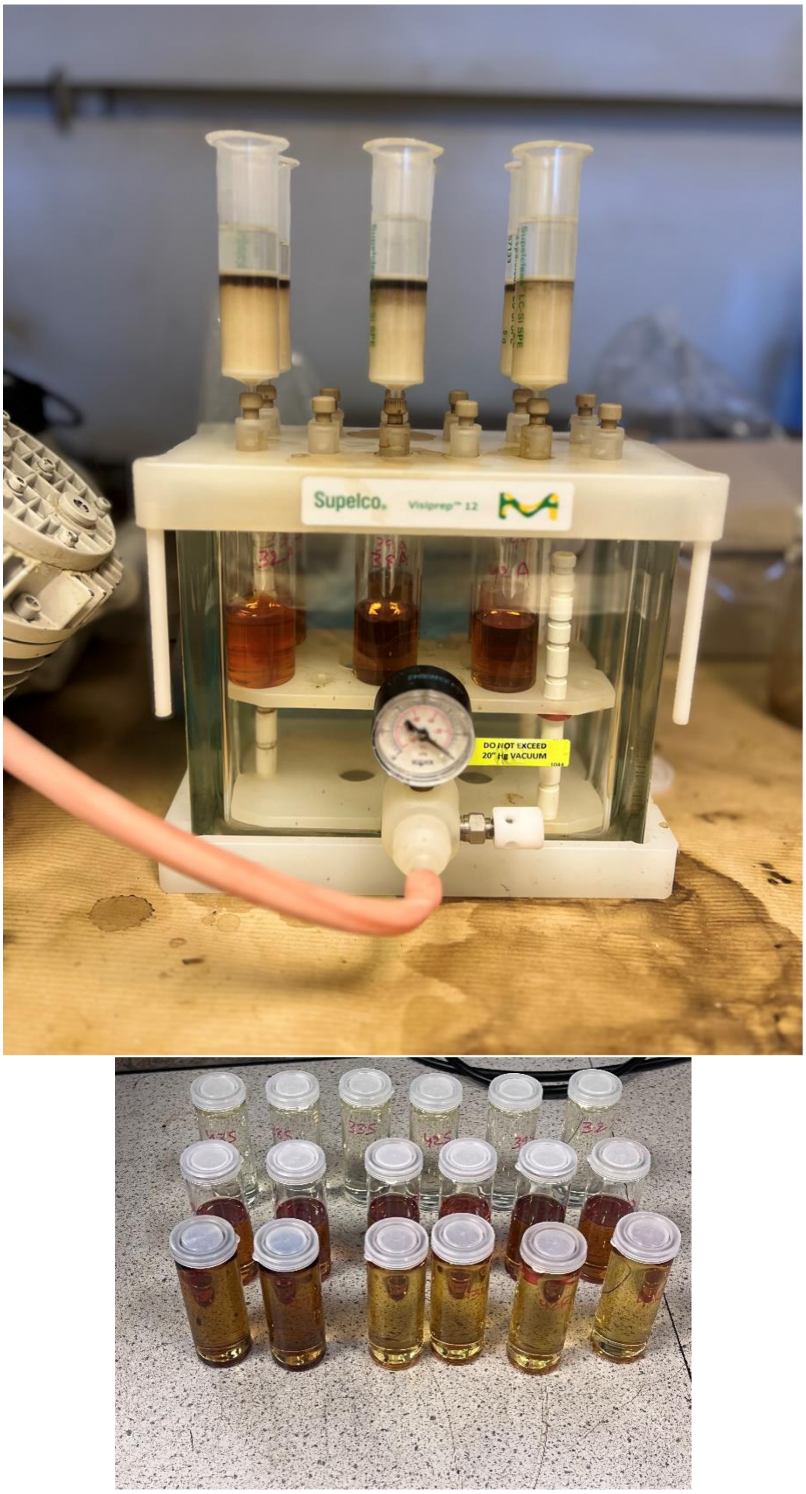


Figure F 1. SARA fractionation