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Performance Comparison of SUPERPAVE and Marshall Asphalt Mix Designs in Relation to Kenya's Climatic Conditions

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Abstract

This study examines the effectiveness of asphalt mixes designed using the Marshall and Superior Performing Asphalt Pavement (SUPERPAVE) methodologies, assessing their suitability for Kenya's diverse climatic conditions and traffic demands. A comprehensive characterisation of materials, including asphalt binders and aggregates, was conducted to ensure compliance with design criteria, followed by performance analyses comparing the two mix design approaches. Laboratory evaluations of hot mix asphalt (HMA) samples focused on key mechanical properties, including indirect tensile strength, Marshall stability, rutting resistance, and moisture susceptibility, to determine their viability for Kenyan road infrastructure. The findings indicate that incorporating Styrene-Butadiene-Styrene (SBS) into 60/70 penetration-grade bitumen substantially enhances strength, thermal stability, and structural integrity, making it highly suitable for high-traffic, high-temperature environments. SUPERPAVE-designed mixes outperformed Marshall mixes by optimising binder content, reducing asphalt usage, and significantly improving resistance to moisture damage, rutting, and long-term deterioration. Marshall stability and indirect tensile strength tests indicated higher initial strength values in SUPERPAVE mixes than Marshall mixes, and they were also more durable following moisture conditioning. Additionally, rut depth analysis confirmed that polymer-modified bitumen enhances rut resistance in SUPERPAVE HMA, outperforming neat bitumen. The study verified that the tested aggregates conform to relevant standards, reinforcing their suitability for high-performance asphalt applications. Given these findings, the study strongly advocates adopting SUPERPAVE as Kenya's climate-responsive, performance-driven pavement design system. It emphasises the need for targeted capacity-building through specialised training programmes, pilot projects with performance monitoring, and economic feasibility assessments integrated with policy advocacy to facilitate its implementation. Furthermore, it calls for developing Kenya-specific binder and aggregate selection standards using the Performance-Graded (PG) system, enforcing stringent quality assurance protocols, and making necessary updates to national road design standards. By prioritising long-term cost efficiency and pavement resilience, the study emphasises the importance of fostering collaboration and knowledge exchange among industry stakeholders, ensuring sustainable advancements in Kenya's road infrastructure.

Keywords: Aggregates, asphalt binders, hot mix asphalt, climatic conditions, Marshall method, pavement performance, road infrastructure, SUPERPAVE, traffic loading

INTRODUCTION

Kenya's diverse climatic conditions played a significant role in the performance and durability of asphalt pavements. The country's tropical climate, characterised by regional variations in temperature, rainfall, and humidity, posed challenges in designing road infrastructure that could withstand environmental stresses. Traditionally, Kenya relied on the Marshall mix design method, which did not adequately account for the impact of moisture and temperature variations on pavement longevity. This limitation highlighted the need to explore alternative approaches, such as the Superior Performing Asphalt Pavement (SUPERPAVE) system, which integrates environmental and traffic-related factors to optimise pavement performance. Developed under the Strategic Highway Research Program (SHRP) in the United States during the late 1980s (Cominsky & National

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Research Council, 1994), SUPERPAVE offered a performance-based methodology that tailored asphalt mixtures to specific climatic conditions. The approach gained global recognition and was successfully implemented in countries such as Jordan (Asi, 2007) and Thailand (Jitsangiam et al., 2013). Given Kenya's unique temperature and traffic conditions, evaluating SUPERPAVE's applicability was fundamental in determining its potential to enhance pavement resilience and extend service life.

This study evaluated the suitability of the SUPERPAVE system for Kenyan roads by identifying appropriate performance-graded (PG) asphalt binders. The PG grading system selects binders based on expected temperature variations to ensure optimal performance under diverse conditions (Garber & Hoel, 2009). The study primarily aimed to compare the performance of asphalt mixes designed using the Marshall and SUPERPAVE methodologies within Kenya's environmental conditions. Specifically, the study assessed the suitability of the SUPERPAVE system for Kenyan roads by characterising asphalt binders and aggregates, comparing the mechanical performance of both methods, and recommending the implementation of binder selection and mix design to enhance pavement durability and performance. By adopting climate-responsive pavement design methods, roads can be better equipped to withstand extreme conditions, improving safety, reducing maintenance costs, and advancing sustainable construction practices.

THEORY

In Kenya and many East African countries, penetration-grade bitumen has been the conventional choice for asphalt pavements, classified based on its penetration depth at 25°C. However, this method fails to represent binder behaviour under fluctuating temperatures fully (Mihretu & Zelelew, 2025). In contrast, the SUPERPAVE PG grading system evaluates binders based on their rheological properties at multiple temperatures, offering a more precise long-term performance assessment. Adopting this performance-based framework would enable a more strategic selection of asphalt binders tailored to Kenya's climatic conditions.

Current asphalt binder testing in Kenya relies on traditional methods focusing on physical characteristics such as ductility, viscosity, and penetration, typically assessed under standard laboratory conditions. Common penetration grades, including 35/50, 40/50, 60/70, and 80/100, adhere to national specifications (*Standard Specifications for Road and Bridge Construction, MoR&PW, 1986*). However, these empirical testing approaches operate within a limited temperature range and lack predictive capability regarding binder performance in real-world applications. The inability to differentiate bitumen types effectively and anticipate long-term behaviour emphasises the necessity of transitioning to a more advanced, climate-responsive evaluation system like SUPERPAVE.

Traditionally, the Marshall mix design method has dominated pavement construction in Kenya due to its simplicity and established usage. However, its emphasis on volumetric properties neglects critical performance factors such as binder rheology and climate resilience. Conversely, SUPERPAVE integrates binder properties, aggregate gradation, and volumetric criteria, optimising mix durability across varying environmental and traffic conditions (Zhao et al., 2021) and (Hu et al., 2020). Comparative studies have consistently demonstrated that SUPERPAVE-designed mixtures outperform Marshall mixes in resisting rutting, moisture-related damage, and cracking, especially when combined with performance-graded binders (Zhao et al., 2021).

International research reinforces SUPERPAVE's advantages where by (Asi, 2007) assessed its performance in Jordan, confirming its superior rutting resistance and durability, qualities that align well with Kenya's climate. Similarly, (Jitsangiam et al., 2013) examined its application in Thailand, identifying limitations in traditional mix designs, including inadequate compaction techniques and inconsistent performance testing. Although their study did not directly propose modifications to mix designs, it highlighted the need for climate-adapted methodologies. Despite its promising attributes, SUPERPAVE remains undocumented mainly in Kenya's pavement research and construction practices. While familiar and straightforward, the continued reliance on the Marshall method does not sufficiently address binder performance under Kenya's diverse climatic and traffic conditions (Zumrawi & Edrees, 2016).

Using SUPERPAVE mix designs, roads such as Malaba-Webuye, Kaburengo-Kakamega, and Ahero-Kisii have been built under the Kenya National Highways Authority (KeNHA). However, since SUPERPAVE's introduction in the late 1990s, no comprehensive evaluations have been conducted to compare their performance against Marshall-designed pavements.

A systematic assessment of SUPERPAVE's effectiveness in Kenya is essential to establish whether its performance-based framework can better accommodate increasing traffic volumes and climatic variability. Limited studies exist on characterising penetration-grade bitumen within the PG system, which hinders the transition to scientifically backed binder selection criteria. Additionally, comparative evaluations of hot mix asphalt (HMA) designed using Marshall and SUPERPAVE techniques are deficient, restricting the ability to make informed, evidence-driven mix design choices. Bridging these research gaps will facilitate the adoption of advanced asphalt pavement design practices, improving infrastructure resilience and long-term performance in Kenya's evolving road network.

RESEARCH METHODS

Materials Characterisation

The materials characterisation process involved collecting asphalt binder and aggregate samples representative of Kenyan construction practices to evaluate their suitability for local climate and traffic conditions. Laboratory tests, including rheological assessments and compatibility studies, were carried out to identify materials that would perform well to implement the SUPERPAVE system effectively.

For asphalt binders, the focus was on commonly used penetration grades (35/50, 50/70, 60/70, 80/100) and polymer-modified asphalt (PMA) blends, particularly 60/70 modified with Styrene-Butadiene-Styrene (SBS). Rheological testing adhered to the SUPERPAVE Performance Grade (PG) system, utilising dynamic shear rheometer (DSR) tests to assess high-intermediate-temperature behaviour. Due to the absence of Bending Beam Rheometer (BBR) equipment, low-temperature properties were estimated at -22°C using industry correlations aligned with Kenya's moderate climatic conditions (ORN 19, Design of Hot Mix Asphalt, 2002). Additional evaluations of the binders included penetration, softening point, flash point, loss on heating, ductility, and solubility analyses, ensuring they were classified into performance grades suitable for local environments.

For aggregates, single-size crushed limestone from Katani Quarry in Mlolongo, Machakos County, was analysed for gradation, particle shape, angularity, and cleanliness. These assessments ensured compliance with the SUPERPAVE volumetric criteria, optimising mechanical stability and durability in asphalt mixtures. This comprehensive approach ensured that locally available materials met the performance standards required for sustainable pavement applications in Kenya.

Asphalt Mix Design Procedures

The comparative evaluation of Marshall and SUPERPAVE mix design methods involved systematically producing HMA samples to assess their performance under heavy traffic conditions. The design process began with selecting optimal aggregate gradation curves, ensuring compliance with the respective method's specifications. Aggregate gradation for the Marshall method followed Kenya's (*Standard Specifications for Road and Bridge Construction, MoR&PW, 1986*), while SUPERPAVE adhered to AASHTO M 323 standards (Asphalt Institute, 2014).

Specimens were prepared with varying asphalt binder content to determine the optimum bitumen content (OBC), which was identified at maximum stability and acceptable flow values. The mix design process focused on achieving key volumetric properties, including air voids (typically 4%), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) to ensure a balance of durability and workability. SUPERPAVE aggregate gradation design considered particle angularity, flat and elongated particles, and sand equivalent values to meet performance criteria.

Further analysis of the mixtures involved evaluating rutting resistance, fatigue resistance, and moisture susceptibility through iterative laboratory testing. These assessments provided insights into the structural integrity of the designed HMA mixtures, ensuring their suitability for Kenya's traffic and environmental conditions.

Figure 1 shows the representation of volumes in a compacted HMA specimen for the Marshall and SUPERPAVE methods adopted from the Asphalt Institute, MS-2, 1994 (ORN 19, Design of Hot Mix Asphalt, 2002).

Performance Testing
Comprehensive laboratory testing assessed the mechanical behaviour of HMA samples designed using the Marshall and SUPERPAVE methods under simulated heavy traffic and Kenya's climatic conditions. These evaluations encompassed indirect tensile strength to gauge resistance to cracking, loss of indirect tensile strength to determine susceptibility to moisture damage, Marshall stability to measure load-bearing capacity, loss of Marshall stability to assess durability under repeated loading, and rutting behaviour to evaluate deformation resistance under sustained traffic conditions. The results provided valuable comparative performance indicators, facilitating an assessment of durability, resilience, and suitability for Kenya's diverse environmental and traffic conditions.

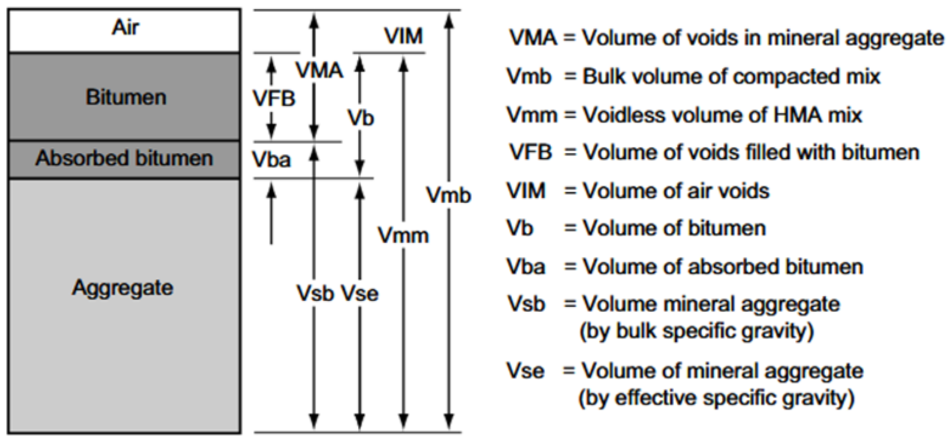


FIGURE 1
Representation of compacted HMA specimen
Source: ORN 19, Design of Hot Mix Asphalt, 2002

RESULTS AND DISCUSSION

Asphalt Binders and Aggregate Characterisation Results

Asphalt Binders
Table 1 provides a comparative physical analysis of various straight-run bitumen samples widely used in Kenya, including penetration grades 35/50, 50/70, 60/70, and 80/100. It outlines essential parameters influencing performance, applicability, and suitability across diverse climatic and traffic conditions. Evaluations of asphalt binders involve testing key characteristics such as penetration, softening point, viscosity, specific gravity, solubility, flash point, and performance grading (PG) to assess their effectiveness.

The penetration test indicated binder hardness, with 35/50, 50/70, and 60/70 grades mostly within specification, while 80/100 was softer than optimal, potentially increasing susceptibility to rutting under heavy loads. Softening point assessments confirmed that most grades had sufficient thermal resistance, though 80/100 posed a deformation risk in high-temperature environments. Viscosity testing at 135°C verified that all grades exhibited appropriate flow characteristics, with 60/70 offering better workability for asphalt production. Specific gravity measurements showed consistency across samples, ensuring reliable asphalt mix performance. High solubility values (99.8–99.9%) affirmed bitumen purity, promoting strong aggregate adhesion and durability. Flash point testing (297–347°C) confirmed safe handling during asphalt processing. Ongoing performance grading (PG) using DSR tests, as shown in **Figure 2** and **Appendix B**, revealed that the 35/50 grade (PG 82-22) suited varied climates, while the 50/70 grade (PG 64-22) performed well in moderate conditions. 60/70 (PG 76-22) proved optimal for high-traffic environments, whereas 80/100 (PG 58-22) showed limitations under heavy loads, favouring lighter traffic applications. This

TABLE 1
Physical analysis for sampled straight-run bitumen available in Kenya

	Bitumen Sample Type		35/50		50/70		60/70		80/100	
No.	Test	Standard Specification	TRs	Criteria	TRs	Criteria	TRs	Criteria	TRs	Criteria
1	Penetration Test at 25 °C, 0.1mm	EN 1426	38.2	35 - 50	54.7	50 - 70	67.2	60 - 70	82.7	80 -100
2	Softening Point (Ring & Ball) Neat, °C	EN 1427	55	50 - 58	54	46 - 54	51	46 - 52	46	40 - 46
3	Viscosity at 135 °C (Virgin), cSt	EN 13302	551	400 - 600	480	400 - 600	345	345 - 400	348	300 - 400
4	Specific Gravity at 25 °C	EN 15326	1.03	1.01 - 1.05	1.03	1.01 - 1.05	1.02	1.01 - 1.05	1.03	1.01 - 1.05
5	Solubility in Trichloroethylene, %	EN 12592	99.9	99.5 - 100	99.8	99.5 - 100	99.8	99.5 - 100	99.8	99.5 - 100
6	Flash Point (Cleveland Open Cup), °C	EN 22592	338	230 - 350	342	230 - 350	347	230 - 350	297	230 -350
7	Performance Grade, (DSR), PG	AASHTO T 315	PG 82-22		PG 64-22		PG 76-22		PG 58-22	
	Resistance to hardening at 163 0C									
8	Retained Penetration, 0.1mm	EN 12591	32.4	28 - 40	51.4	40 - 60	58.5	45 - 65	77.9	60 - 80
9	Increase in Softening Point, °C	EN 1427	2	1 - 4	3	2 - 5	2	2 - 5	2	2 - 5
10	Thin Film Oven Test (TFOT), cm	EN 12607-1	0	0 - 0.3	0.2	0 - 0.3	0.2	0 - 0.3	0.2	0 - 0.3
11	Loss on Heating, %	EN 12607-2	0	0 - 0.5	0.2	0 - 0.5	0.1	0 - 0.5	0.2	0 - 0.5
12	Ductility at 25°C after RTFOT, cm	EN 1426	95	90 min	100+	75 min	100+	80 min	100+	90 min
TRs*- (Test Results)										

Source: Field survey, 2025

FIGURE 2
Ongoing evaluation of rheological properties of neat bitumen binders using DSR
Source: Field survey, 2025

comprehensive analysis ensures informed binder selection for Kenya's durable and climate-resilient asphalt pavement solutions.

The evaluation above confirms that the tested bitumen binders meet the essential performance criteria for asphalt pavement applications in Kenya's varied climatic conditions. Each grade exhibits distinct strengths and limitations, influencing its suitability based on expected traffic loads and environmental factors. Proper grade selection is vital for enhancing pavement durability and longevity, mitigating potential failures.

Figure 3 shows a high-shear mixer mixing asphalt binder (60/70) and SBS, while DSR test data are captured in **Appendix B**. The analysis in **Table 2** highlights the significant impact of SBS modification on the performance of 60/70 penetration grade bitumen. As SBS content increases, penetration values decrease. However, at 4.7% SBS, penetration falls below the standard range, suggesting excessive hardening that may affect workability. The softening point increases, improving thermal resistance, which is essential for hot climates as it reduces susceptibility to rutting. Elasticity improves, with recovery percentages exceeding 60%, minimising the risks of cracking and ensuring better load distribution. The binder retains elasticity despite oxidative and thermal stress, reinforcing long-term durability. While dynamic viscosity rises with higher SBS content, values remain within permissible limits, ensuring smooth mixing and paving. High flashpoint temperatures (≥230°C) confirm thermal stability, reducing overheating risks during processing. All tested formulations maintain a PG 82-22 classification, demonstrating the binder's ability to withstand extreme heat (up to 82°C) without degradation and cold conditions (-22°C) while retaining flexibility, preventing brittleness and cracking.

Among the tested formulations, 4.2% of SBS-modified bitumen exhibits the best balance between stiffness, elasticity, and thermal resistance. This concentration effectively enhances durability and adaptability, making it suitable for heavy traffic zones and extreme temperature conditions. Given Kenya's variable climate, integrating SBS-enhanced asphalt into pavement designs ensures superior resistance to expansion and contraction cycles, mitigating thermal cracking and premature wear.

The evaluation of Performance Grade (PG) test results emphasises the substantial improvements offered by SBS modification, ensuring superior performance across a broad temperature range. These findings reinforce the suitability of SBS-enhanced binders for challenging climatic conditions and heavy-duty road construction.

FIGURE 3
Mixing of 60/70 penetration grade bitumen and SBS using High-Shear Mixer
Source: Field survey, 2025

TABLE 2
60/70 PMA analysis at 3.7%, 4.2% and 4.7% of SBS

			SBS % added to 60/70			
No.	Test	Standard Specification	3.7	4.2	4.7	Criteria
1	Penetration, 0.1mm	EN 1426	66.7	62.5	46.4	60 -70
2	Softening point, °C	MB – 17	62	79	81	65-85
3	Elastic Recovery at 15 °C, %	MB – 4	78	83	89	>60
4	Dynamic Viscosity at 165 °C, Pa.s	MB – 18	0.380	0.422	0.468	<0.600
5	Flashpoint, °C	ASTM D92	353	365	361	≥230
6	Performance Grade (DSR), PG	AASHTO T 315				
	PG 82-22	PG 82-22	PG 82-22			
Properties after ageing (RTFOT), MB -3						
7	Difference in Softening point, °C	MB – 17	1	3	3	-2 to +8
8	Elastic Recovery at 15 °C, %	MB – 4	53	71	76	>50
9	Mass change, %	MB – 3	0	0	0	≤1.0

Source: Field survey, 2025

Specifically, where temperature variability is notable in Kenya, polymer-modified binders, particularly SBS-enhanced asphalt, improve elasticity and thermal stability, allowing pavements to endure expansion and contraction cycles without significant deterioration. Incorporating regional climate data into binder selection ensures resilient, durable, and well-adapted pavements for Kenya's environmental conditions.

Aggregates
Table 3 presents the physical properties of the coarse aggregates utilised in this study. It assesses their performance against established design criteria from Kenya's (*Road Design Manual, Part III, MT&C, 1987*) for heavy traffic beyond 30 million Equivalent Single Axle Loads (ESALs). The results reveal that the aggregates exhibit commendable characteristics that suggest their suitability for high-performance asphalt concrete applications.

Key properties such as the Los Angeles Abrasion (15.1%), Aggregate Crushing Value (18.5%), and Sodium Sulphate Soundness (1.4%) are notably below the maximum specified thresholds, indicating excellent durability and resistance to mechanical wear and environmental degradation. The low values for Los Angeles Abrasion and Aggregate Crushing Value imply that these aggregates will likely provide a robust foundation for asphalt pavements, ensuring longevity even under heavy traffic conditions. Moreover, the high 10% Fines Value (248 kN) signifies strong aggregate interlock and mechanical stability within the asphalt mix, further contributing to the pavement's structural integrity. The Sand Equivalent tests (87.8% for 0/6mm and 74.5% for 0/3mm) show adequate cleanliness, essential for achieving optimal bonding between the aggregates and the binder.

These good physical properties suggest that the coarse aggregates are well-suited for asphalt concrete design. They can significantly enhance the performance and durability of road surfaces in Kenya, especially in areas with heavy loads and fluctuating climatic conditions. As detailed in **Appendix E**, a sieve analysis was conducted to determine the combined specific gravity, water absorption and maximum specific gravity for Aggregates to be used in the Marshall & SUPERPAVE Methods. **Appendix A** shows photos of the progress of laboratory tests conducted for the study.

TABLE 3
Physical properties of coarse aggregates used

No.	Test Description	Test standard	Test value	Design Criteria per Road Design Manual, Part III, MT&C, 1987
1	Los Angeles Abrasion, LAA (%)	AASHTO T96	15.1	30 Max
2	Aggregate Crushing Value, ACV (%)	BS 812:110	18.5	25 Max
3	Sodium Sulphate Soundness, SSS (%)	BS 812:121	1.4	5 Max
4	Aggregate Impact Value, AIV (%)	BS 812: 112	13.2	20 Mix
5	10% Fines Fact Value, FFV (KN)	BS 812:111	248	150 Min
6	Sand Equivalent (0/6mm) (%)	AASHTO T176	87.8	45 Min
7	Sand Equivalent (0/3mm) (%)	AASHTO T177	74.5	45 Min

Source: Kenya's (Road Design Manual, Part III, MT&C, 1987)

Optimum Mix Designs from Marshall and SUPERPAVE Methods

Marshall Method of Mix Design
Following recommendations from the (Asphalt Institute, 2014) & (ORN 19, Design of Hot Mix Asphalt, 2002), the Marshall mix design procedure, ensures optimal aggregate gradation and binder content for heavy traffic loads under varying climatic conditions. A sieve analysis was conducted to determine the proper gradation and proportions of selected aggregates, meeting the required specifications. **Figure 4** presents the gradation chart of single-size and combined aggregate blends, including 14/20mm, 10/14mm, 6/10mm, 0/6mm, and 0/3mm sizes. The detailed grading for the aggregates is captured in **Appendix C**.

The Marshall asphalt concrete mix design procedure (AASHTO T 245), utilising a 10.16 cm sample diameter, is the standard approach in Kenya (Asphalt Institute, 2014). To determine the optimum bitumen content (OBC), the study followed Kenya's (*Standard Specifications for Road and Bridge Construction, MoR&PW, 1986*) for heavy traffic binder courses. Specimens were moulded with binder contents ranging from 4.5% to 6.2% (in increments of 0.5% by weight of mineral aggregates). Each specimen was compacted using

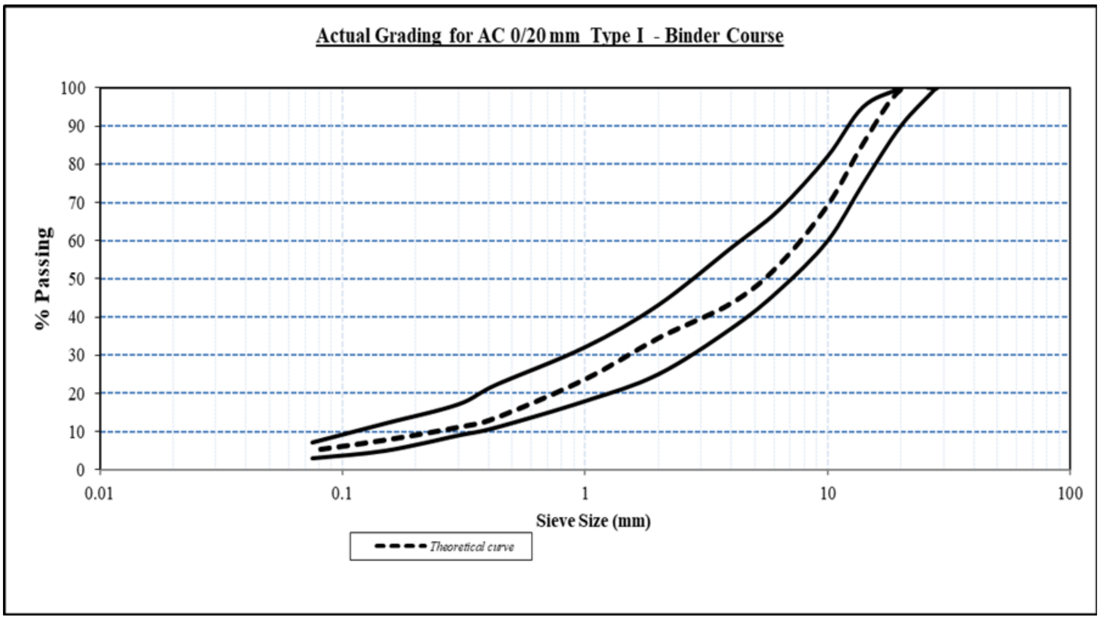


FIGURE 4
Gradation chart of aggregates for ACWC 0/20mm, Type 1- Binder Course
Source: Field survey, 2025

a Marshall compactor, applying 75 blows on both sides to simulate field conditions for heavy traffic.

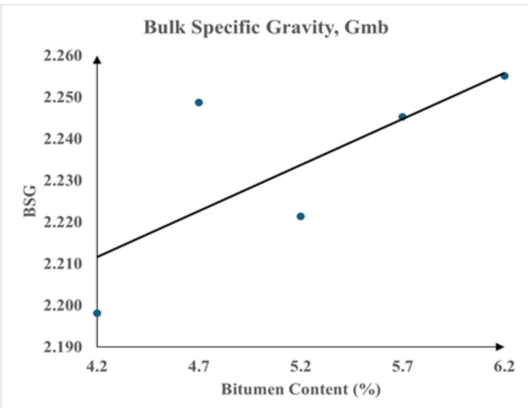
Comprehensive test results, including bulk density, stability, flow value, and volumetric properties, were analysed. **Table 4** summarises the Marshall specimen trial design parameters for Asphalt Concrete (AC) and specified limits. At the same time, the whole dataset and applied formulas are provided in **Appendix F**. Calculations were conducted using Excel spreadsheets to ensure precision and efficiency. **Figure 5** presents Marshall Mix design volumetric property curves, illustrating the mix's performance characteristics. Marshall test specimens underwent bulk density, stability, and flow value assessments to confirm compliance with Kenya's design parameters for HMA. The primary objective was to determine OBC that achieves 4% air voids, ensuring durability while minimising permeability.

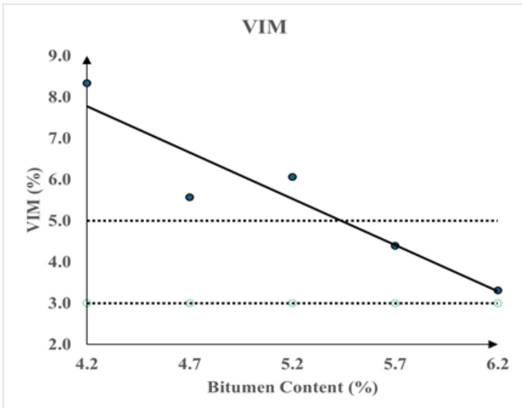
Using the Asphalt Institute MS-2 method, the OBC was calculated based on a 4.0% design air void content (VIM). All key parameters, including voids in mineral aggregate (VMA), voids filled with bitumen (VFB), stability, flow, and dust binder content, met specified limits, affirming a well-balanced mixture. The study determined that the optimum binder content for the Marshall mix was 5.88% by aggregate weight, reinforcing the method's emphasis on stability and flow to support heavy traffic loads.

TABLE 4
Marshall trial design parameters of AC and specified limits

% Bitumen by wt. of mix, Pb	Bulk S.G. Specimen, Gmb	Bulk S.G Aggregate, Gsb	Effective S.G. Agg., Gse	Max. S.G. (Loose Mix), Gmm	% Air Voids (VIM)	%VMA	%VFB	Stability, kN	Flow (0.25 mm)	Dust Binder Ratio
4.2	2.198	2.470	2.549	2.398	8.3	14.7	43.5	15.7	2.5	0.9
4.7	2.249	2.470	2.549	2.381	5.6	13.2	57.9	16.1	2.8	1.0
5.2	2.221	2.470	2.549	2.365	6.1	14.7	58.9	12.0	2.1	1.1
5.7	2.245	2.470	2.549	2.348	4.4	14.3	69.3	12.2	2.6	1.2
6.2	2.255	2.470	2.549	2.332	3.3	14.4	77.0	11.5	2.9	1.3
Design Criteria Requirements					**3-5%**	**>13%**	**65-75%**	**9-18kN**	**2-4 mm**	**0.6-1.2**

Source: Kenya's (Standard Specifications for Road and Bridge Construction, MoR&PW, 1986)





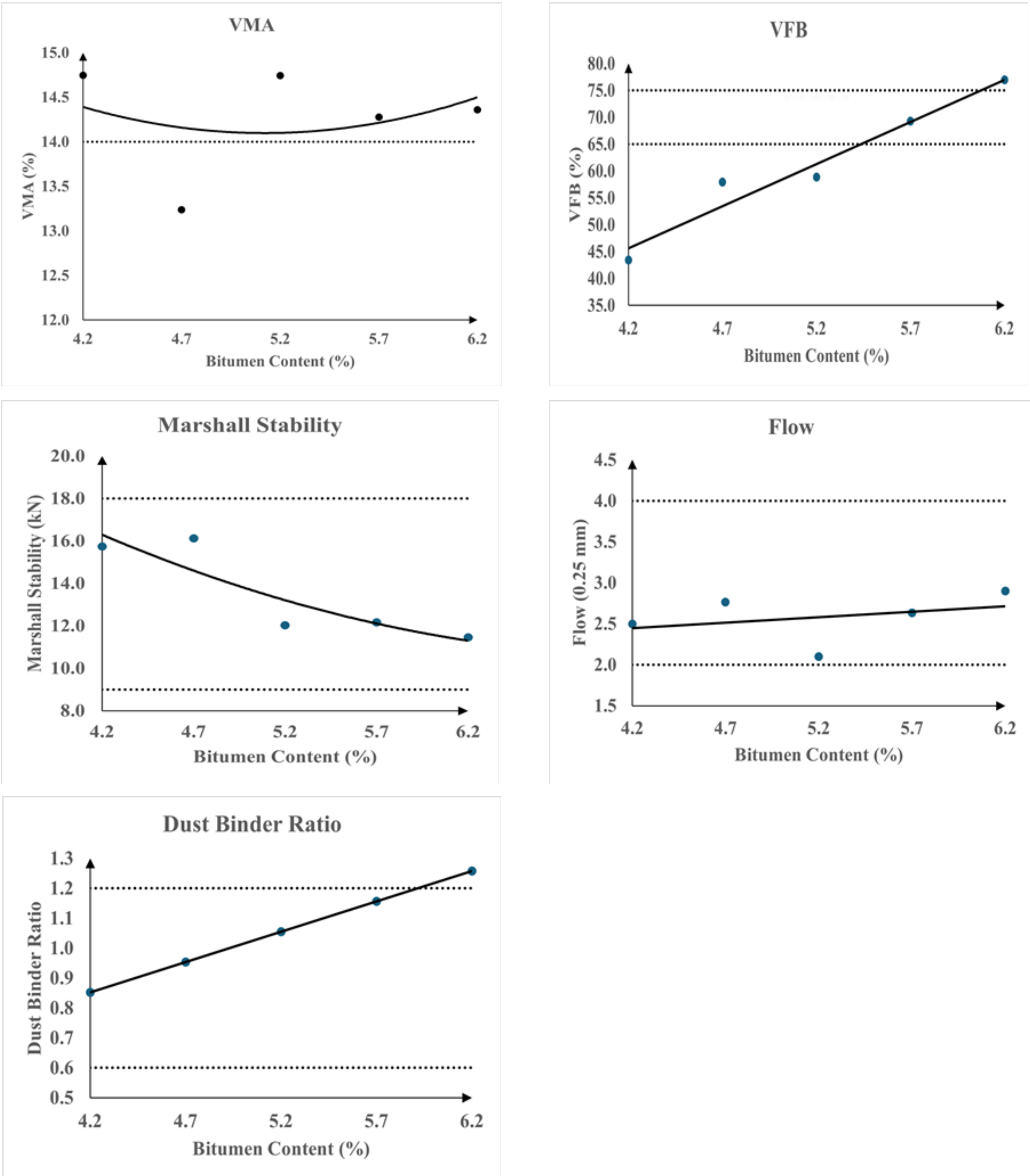


FIGURE 5
Marshall mix design curves
Source: Field survey, 2025

SUPERPAVE Method of Mix Design

The SUPERPAVE mix design method, utilising the SUPERPAVE gyratory compactor (SGC), focuses on selecting an aggregate structure that meets specific gradation requirements, ensuring optimal mechanical stability, drainage, and overall performance of asphalt mixtures. Aggregate gradation is engineered to maximise density and optimise voids, following the 0.45 power gradation graph guidelines (ORN 19, Design of Hot Mix Asphalt, 2002).

SUPERPAVE incorporates a Performance-Grade binder selection based on climatic conditions at the pavement's location. This study utilised locally sourced bitumen (60/70), chosen for its ability to withstand temperature extremes identified through detailed climate analysis. The gradation of heavy traffic load aggregates for the Asphalt Concrete Base Course (ACBC) with a 19.0 mm Nominal Maximum Size (NMS) SUPERPAVE mix was evaluated (Asphalt Institute, 2014). Results in **Figure 6** indicate that the SUPERPAVE recommended gradation passes through the restricted zone, necessitating special compaction precautions during field applications. **Appendix**

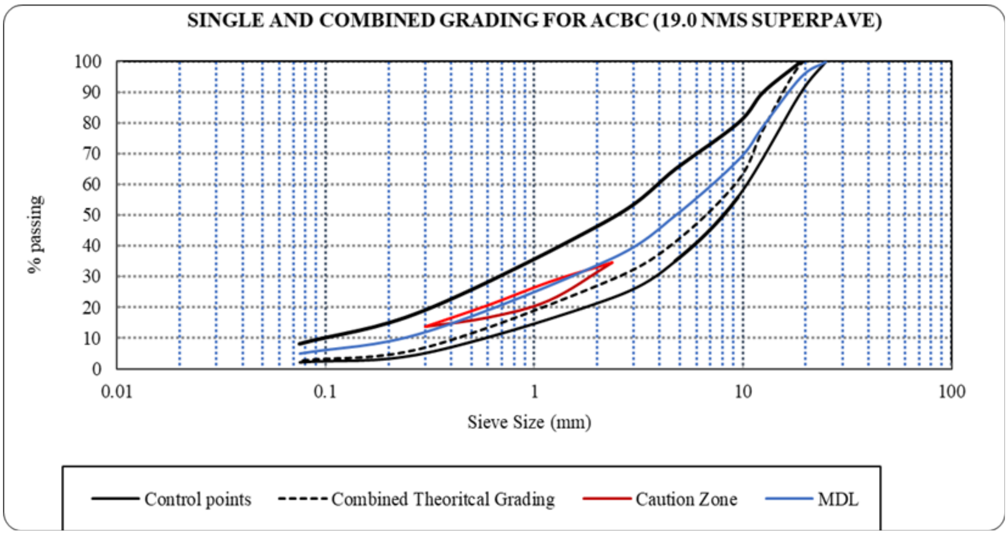


FIGURE 6
Single and Combined grading for ACBC (19.0mm NMS SUPERPAVE)
Source: Field survey, 2025

D shows detailed grading for SUPERPAVE.

Introducing the gyratory compactor into SUPERPAVE mix design requires the specification of gyratory levels for compacting asphalt trial mixes. These gyration parameters depend on the average design of high air temperature and Equivalent Single Axle Loads (ESALs). This study selected a traffic level exceeding 30 million ESALs, reflecting the conditions of Kenya's international trunk road network, which experiences a warm average air temperature of 35°C. According to (ORN 19, Design of Hot Mix Asphalt, 2002) the designated gyrations levels applied were:
• Ninitial = 9 gyrations
• Ndesign = 125 gyrations
• Nmaximum = 205 gyrations

SUPERPAVE mixes were prepared with blended mineral aggregates, incorporating incremental binder content variations from 4.2% to 6.2% by aggregate weight. Each binder content level was tested using three compacted specimens to ensure consistency.

The resultant data, summarised in **Table 5**, provides insights into critical mix properties, including %Gmm at Ninitial, voids in mix (VIM), voids in mineral aggregate (VMA), voids filled with bitumen (VFB), %Gmm at Nmax, and dust-to-binder ratio, key parameters for achieving optimal binder content (OBC) at 4% air voids. The comprehensive results, applied formulas, and calculated values are detailed in **Appendix G**. **Figure 7** presents SUPERPAVE design volumetric property curves, illustrating the mix's performance characteristics.

Given Kenya's high rainfall variability, moisture susceptibility was assessed via the AASHTO T-283 test, which measures the mix's ability to retain strength after exposure to moisture (Asphalt Institute, 2014). The stability values of conditioned and unconditioned samples were compared to determine the risk of moisture-induced damage, which influenced binder content selection. The trial asphalt binder content for the five SUPERPAVE blends was estimated at 5.20%, ensuring optimal workability and cost efficiency.

The optimum bitumen content, determined through bitumen binder and aggregate analysis for both Marshall and SUPERPAVE mixes, highlights their unique design approaches, where:
- The Marshall mix required an OBC of 5.88%, emphasising stability and flow, in line with traditional design approaches.
- The SUPERPAVE mix identified an OBC of 5.20%, optimising binder content for mechanical durability, volumetric balance, and minimised excess binder usage.

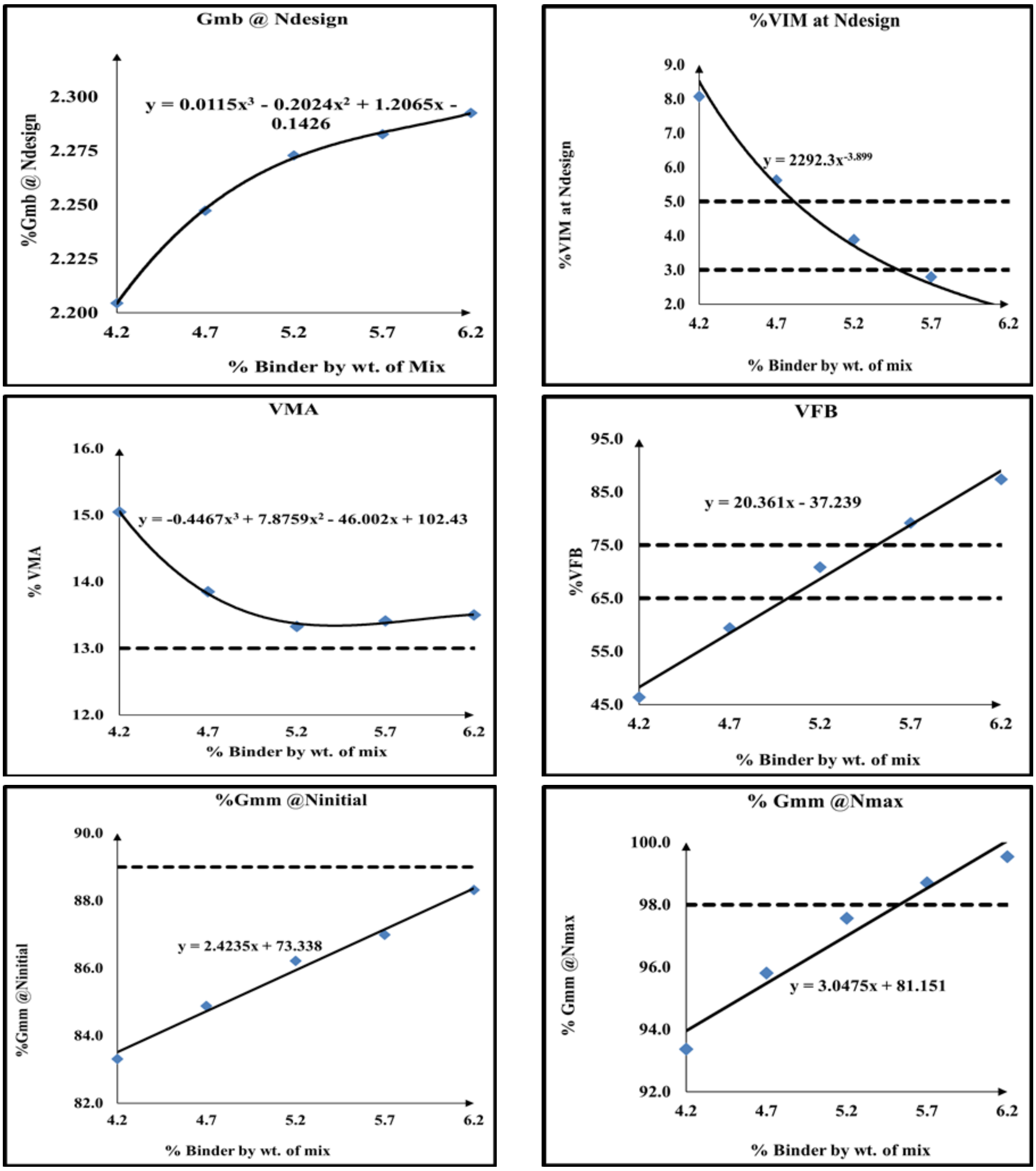
Aggregate gradation differed significantly between the two methodologies. SUPERPAVE enforces strict controls on aggregate shape, angularity, and gradation, producing highly resistant mixtures

TABLE 5

Compacted specimen volumetric property summary for SUPERPAVE

Composition of SUPERPAVE Mixtures (Analysis by mass of total mixture)								
Binder Content, %	Max. Sp.Gr.	%Gmm at Ninitial	Volumetrics at Ndesign (125 cycles)				%Gmm at Nmax	Dust Binder Ratio
			%Gmb	%Air voids (VIM)	%VMA	%VFB		
4.2	2.398	83.3	2.205	8.1	15.0	46.4	93.4	0.98
4.7	2.381	84.9	2.247	5.6	13.8	59.4	95.8	0.84
5.2	2.365	86.2	2.273	3.9	13.3	70.9	97.6	0.74
5.7	2.348	87.0	2.283	2.8	13.4	79.2	98.7	0.66
6.2	2.332	88.3	2.293	1.7	13.5	87.4	99.5	0.59
		<89%		3 - 5%	>13%	65 - 75%	<98%	0.6 - 1.2

Source: Asphalt Institute, 2014



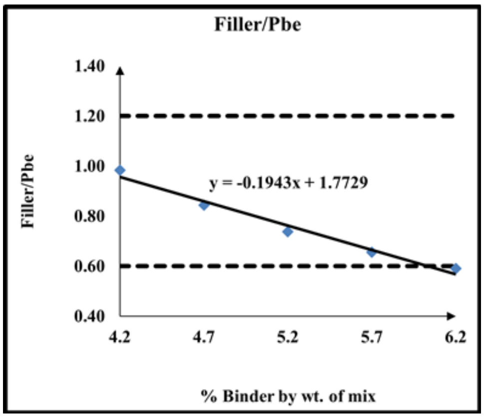


FIGURE 7
SUPERPAVE design curves
Source: Field survey, 2025

that withstand deformation while improving load distribution and rut resistance under heavy traffic conditions. Conversely, Marshall mix design follows conventional gradation specifications without detailed refinements in angularity or sand equivalent values, potentially reducing long-term durability.

SUPERPAVE's advanced performance-driven methodology customises binder content and aggregate structure to enhance asphalt mix resilience across varying environmental and traffic conditions. Enforcing precise volumetric controls ensures sustained pavement durability, minimised maintenance needs, and cost-effective road construction. Its application in Kenya's road infrastructure development can significantly enhance pavement longevity, optimise load resistance, and reduce susceptibility to premature degradation.

Comparative Mechanical Performance Test Results

HMA sample sets were prepared for mechanical performance testing, ensuring compliance with specified gradation requirements for each mix design methodology. The optimum bitumen content selected for the SUPERPAVE mix was 5.20%, while the Marshall mix required 5.88%, reflecting the fundamental methodological differences between these two approaches. Marshall specimens were compacted with 75 blows on both sides to simulate Kenya's heavy traffic loading conditions, while SUPERPAVE specimens underwent 205 gyrations to achieve optimal density and structural integrity. Comprehensive mechanical tests were conducted on Marshall and SUPERPAVE compacted specimens. They strictly evaluated their performance characteristics, including load resistance, durability, and susceptibility to deformation, ensuring reliability under real-world traffic and environmental conditions.

Test Results for ITS & loss of ITS (AASHTO T-283)

The Indirect Tensile Strength (ITS) test evaluates the tensile properties of asphalt mixtures and their resistance to cracking by applying a diametrical compressive load to measure tensile stress at failure. It also assesses moisture susceptibility, simulating environmental effects on pavement durability through wet conditioning (Asphalt Institute, 2014). **Appendix H** details comprehensive results, applied formulas, and calculated values.

a) Performance of SUPERPAVE vs. Marshall Mix Designs Based on ITS Values (Neat Samples)

The ITS test results from **Figure 8** reveal distinct performance differences between SUPERPAVE and Marshall mixes. SUPERPAVE mixtures demonstrated superior initial tensile strength, averaging 943 kPa, compared to 870 kPa for Marshall mixes. This indicates greater cracking resistance under heavy traffic loads.

After moisture conditioning to simulate real-world exposure, SUPERPAVE mixes retained a higher conditioned tensile strength of 851 kPa, while Marshall samples showed a lower average of 769

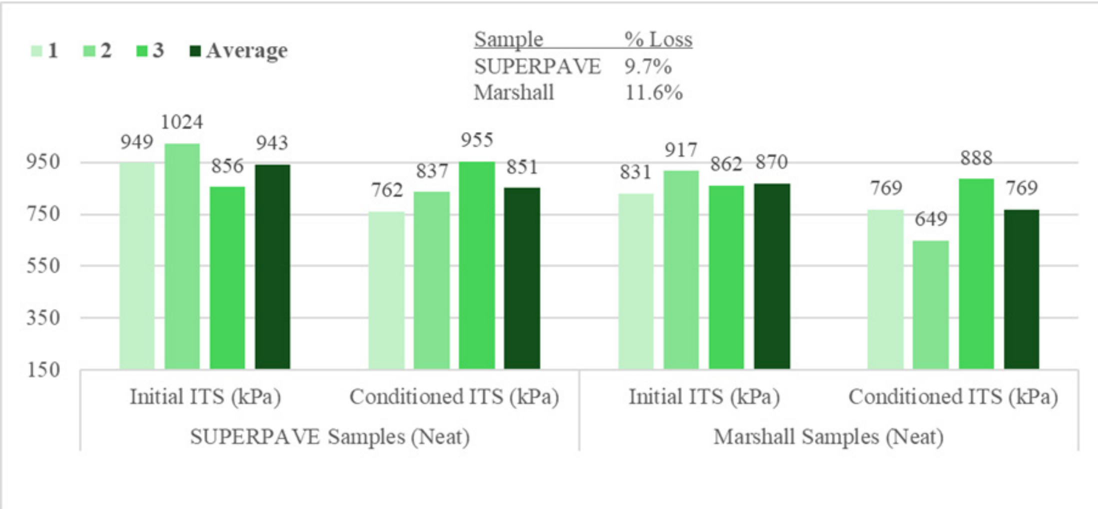


FIGURE 8
ITS graph results for SUPERPAVE and Marshall neat samples
Source: Field survey, 2025

kPa. The ability of SUPERPAVE mixes to maintain tensile strength and post-conditioning signifies their resilience against moisture-induced damage. Additionally, SUPERPAVE mixtures exhibited a lower percentage loss in tensile strength at 9.7%, compared to 11.6% for Marshall mixes, confirming their enhanced moisture resistance and durability.

These findings highlight SUPERPAVE-designed mixes' structural integrity and performance reliability, particularly in regions like Kenya, where variable humidity and rainfall can accelerate moisture-related pavement deterioration. The improved elasticity, durability, and resistance to environmental stresses make SUPERPAVE mixtures well-suited for long-lasting road infrastructure in challenging climatic conditions.

b) Performance of SUPERPAVE vs. Marshall Mix Designs Based on ITS Values (PMA Samples)

Figure 9 of the ITS test reveals significant performance differences. SUPERPAVE PMA samples exhibit superior initial tensile strength, averaging 912 kPa, compared to 780 kPa for Marshall PMA samples. This notable difference confirms that SUPERPAVE mixes provide greater resistance to traffic-induced stresses, making them more suitable for high-load applications.

Moisture conditioning further highlights this performance gap, with conditioned ITS values for SUPERPAVE PMA samples averaging 846 kPa, significantly higher than the 664 kPa observed in Marshall PMA samples. The retention of tensile strength after conditioning demonstrates SUPERPAVE's superior resistance to moisture-induced degradation, demonstrating its durability in environments prone to water infiltration.

The percentage loss in ITS also reinforces the resilience of SUPERPAVE mixes, which recorded a 7.3% reduction compared to a much higher 14.9% loss in Marshall PMA samples. This lower percentage loss further validates SUPERPAVE's ability to mitigate moisture-related distress, ensuring long-term pavement stability. In contrast, Marshall mixes are more susceptible to moisture damage, suggesting that PMA modification may not adequately reinforce their structural integrity.

Overall, SUPERPAVE PMA mixes are high-performance solutions, offering enhanced tensile strength, superior moisture resistance, and long-term durability, making them ideal for demanding traffic and environmental conditions. Meanwhile, Marshall PMA mixes may require additional adjustments to fully capitalise on the benefits of polymer modification. These findings reaffirm that PMA modification is most effective within the SUPERPAVE design framework, particularly for ensuring pavement longevity and resilience in varying climatic conditions.

From Equation 1 in **Appendix E**, the percentage increase in ITS when SBS is incorporated in the SUPERPAVE mixes resulted in a reduction of ITS values rather than an increase, which could be due

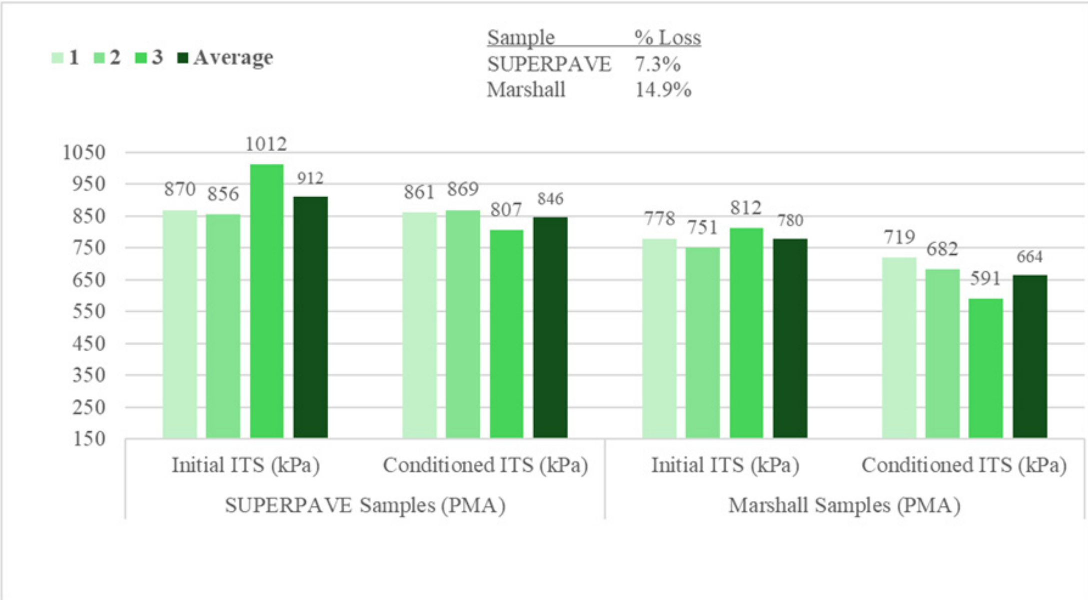


FIGURE 9
ITS graph results for SUPERPAVE and Marshall PMA samples
Source: Field survey, 2025

to specific mix characteristics or other influencing factors like binder content, aggregate gradation, or moisture susceptibility.

Test Results for Marshall stability and Loss of Marshall stability (AASHTO T 165)

The Marshall Stability Test (AASHTO T 165) evaluates asphalt mix strength and resistance to permanent deformation by measuring the maximum load before failure (stability) and deformation at peak load (flow) (Asphalt Institute, 2014). This ensures pavement durability under varying traffic conditions. Additionally, the moisture susceptibility test assesses stability, retention, and potential for stripping by exposing specimens to repeated moisture conditioning cycles. The comprehensive results, applied formulas, and calculated values are detailed in **Appendix I.**

a) Performance of SUPERPAVE vs. Marshall Mix Designs based on Marshall stability Values (Neat Samples)

Figure 10 demonstrates that SUPERPAVE mixes achieved an impressive average initial stability of 16,933 N, notably exceeding the 15,028 N recorded for Marshall mixes. The greater load-bearing capacity of SUPERPAVE designs indicates their suitability for heavy-duty applications, where superior structural integrity is vital. After moisture conditioning, SUPERPAVE neat samples retained an average stability of 15,692 N, outperforming the Marshall neat samples, which fell to 14,540 N. The consistent advantage of SUPERPAVE mixes following conditioning highlights their ability to maintain structural integrity over time, minimising performance deterioration under real-world environmental conditions. Moreover, the percentage loss in stability for SUPERPAVE neat samples was 7.3%, significantly lower than the 10.1% observed in Marshall mixes. This reduced stability loss confirms the enhanced resistance of SUPERPAVE mixtures to deformation and moisture-induced distress, ensuring long-term pavement durability in areas with variable climatic conditions.

These findings position SUPERPAVE mix design as a more resilient and reliable solution for asphalt pavement construction, particularly in its neat formulation. Its superior stability, reduced susceptibility to environmental degradation, and enhanced durability make it the preferred choice for high-performance roads. Given the traffic loads and climatic variability in regions like Kenya, adopting SUPERPAVE mixes could significantly enhance pavement longevity and reliability, leading to more sustainable road infrastructure.

b) Performance of SUPERPAVE vs. Marshall Mix Designs based on Marshall Stability Values

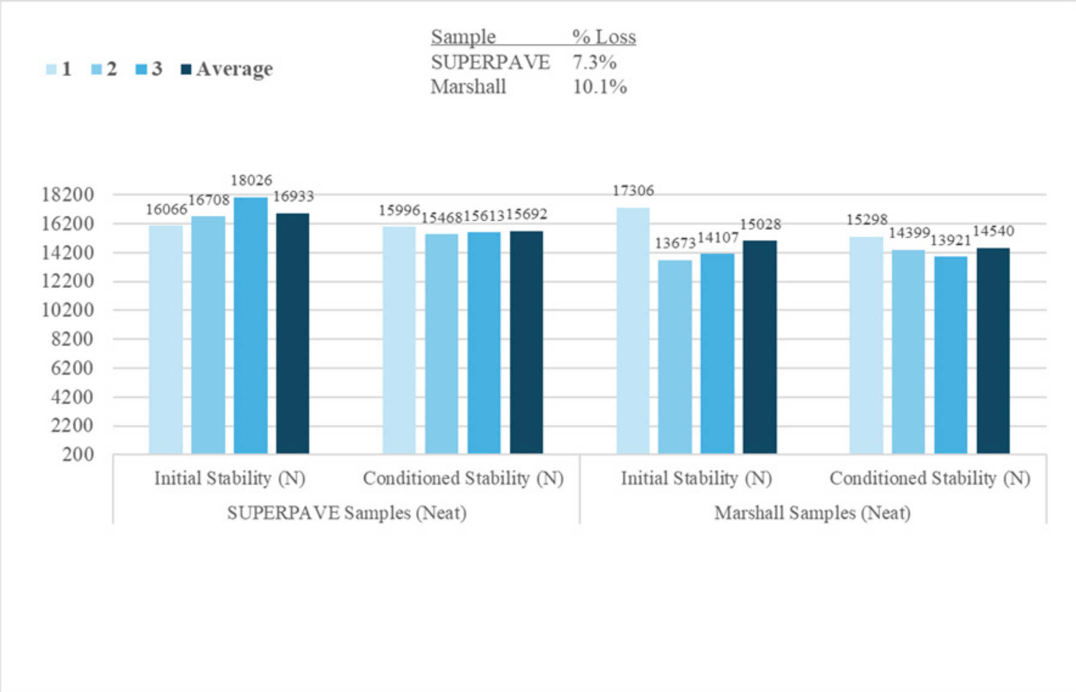


FIGURE 10
Marshall stability graph results for SUPERPAVE and Marshall neat samples
Source: Field survey, 2025

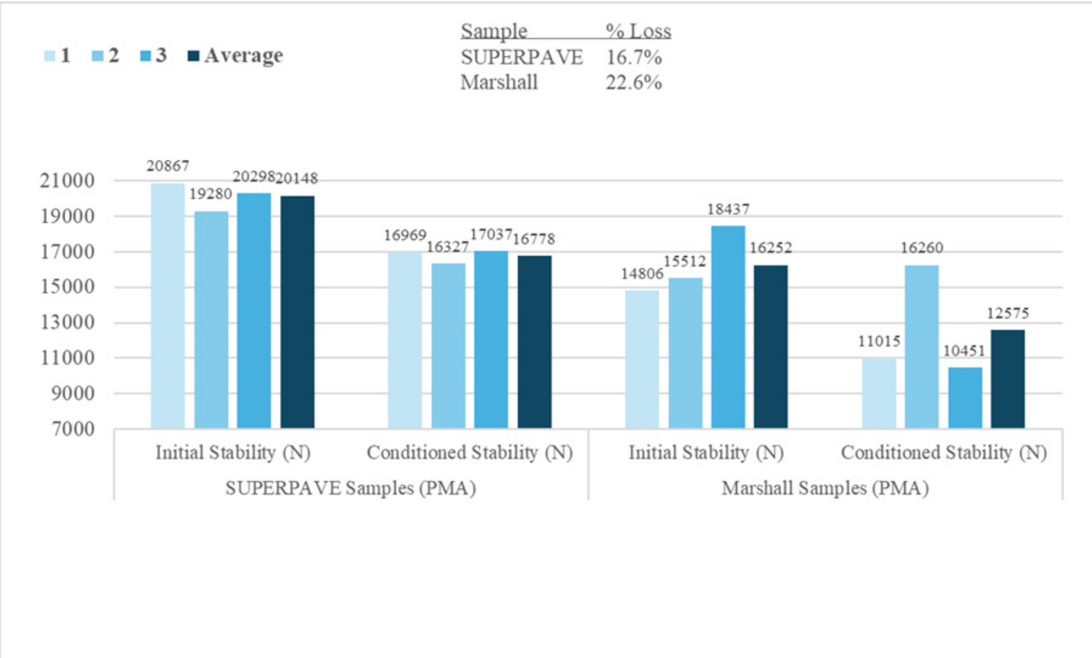


FIGURE 11
Marshall stability graph results for SUPERPAVE and Marshall PMA samples
Source: Field survey, 2025

(PMA Samples)

Initial stability values for SUPERPAVE PMA samples averaged 20,148 N, considerably exceeding the 16,252 N recorded for Marshall PMA samples in **Figure 11**. This demonstrates an enhanced load-bearing capacity that is essential for withstanding high-traffic environments. Following moisture conditioning, the SUPERPAVE mix retained 16,778 N, outperforming the Marshall mix, which averaged 12,575 N. This suggests that SUPERPAVE designs provide greater structural integrity and long-term reliability, particularly in challenging environmental conditions. The percentage loss in stability, an essential indicator of resistance to deformation and moisture-induced damage, further demonstrates SUPERPAVE's advantages. The SUPERPAVE PMA mix exhibited a lower percentage loss of 16.7%, compared to 22.6% for Marshall PMA, confirming its superior durability and extended service life.

These findings establish SUPERPAVE mix designs, especially those with polymer modifications, as more resilient and durable asphalt solutions. Their enhanced stability, reduced susceptibility to moisture damage, and cost-effective maintenance make them a strategic choice for pavement construction in Kenya, where climatic variability and heavy traffic loads present significant challenges. Adopting SUPERPAVE can improve pavement longevity, lower maintenance costs, and ensure reliable performance in demanding conditions.

From Equation 2 in **Appendix E**, SBS incorporation significantly improves initial stability for both SUPERPAVE and Marshall mixes, but in conditioned stability, Marshall mixes saw a decline, whereas SUPERPAVE still benefited. This suggests that SBS enhances stiffness but may affect moisture durability in Marshall mixes.

Rut depth test results (EN 12697-22)

This study evaluates the rutting resistance of SUPERPAVE hot mix asphalt (HMA) using the Hamburg Wheel Tracking Test, conducted under BS EN 12697-22 (Bituminous Mixtures. Test Methods for Hot Mix Asphalt Wheel Tracking, 2007). Rutting, a central distress mechanism in asphalt pavements, leads to permanent deformation and reduced longevity, especially under repeated traffic loads. By simulating wheel loading conditions, this test assesses the susceptibility of SUPERPAVE HMA mixtures to deformation.

The investigation examines the rut depth performance of SUPERPAVE HMA prepared with aggregates blended with two distinct bitumen variants: 5.2% neat bitumen (60/70 penetration grade) and 5.2% polymer-modified bitumen (60/70 penetration grade with 4.2% styrene-butadiene-styrene (SBS)). These formulations ensure consistency in testing conditions. The study builds on prior assessments that confirmed the SUPERPAVE mix design's superior performance over the traditional Marshall method, further reinforcing its effectiveness in mitigating rutting and enhancing pavement durability.

Table 6 and **Appendix J** present rut depth measurements for SUPERPAVE HMA samples, providing valuable insights into their deformation resistance under traffic loads. Neat HMA

TABLE 6

Rut depth test results for the SUPERPAVE HMA sample for neat and polymer modified

Bitumen Type Used in the Mix Design	Test Sample for HMA	Measured Rut Depth (mm)	EN 12697-22 Requirement (mm)
5.2% of 60/70 Penetration Grade Bitumen (neat)	Neat 1	9.04	≤ 10.0
	Neat 2	8.42	≤ 10.0
	Neat 3	5.36	≤ 10.0
	Neat 4	7.61	≤ 10.0
Average (Neat)	-	7.48	≤ 10.0
5.2% of 60/70 Penetration Grade Bitumen + 4.2% SBS (Polymer modified)	Modified 1	3.88	≤ 5.0
	Modified 2	6.22	≤ 5.0
	Modified 3	3.43	≤ 5.0
	Modified 4	2.41	≤ 5.0
Average (Modified)	-	3.99	≤ 5.0

Source: Field survey, 2025

samples exhibit an average rut depth of 7.48 mm, remaining within the EN 12697-22 limit of ≤10 mm. However, variations among individual samples reveal differences in performance, with Neat 1 (9.04 mm) and Neat 2 (8.42 mm) showing increased deformation, indicating heightened susceptibility to rutting under heavy traffic conditions. Conversely, polymer-modified HMA samples display superior rut resistance, averaging 3.99 mm below the ≤5 mm threshold. Nonetheless, modified 2 (6.22 mm) slightly surpasses the recommended limit, suggesting potential refinements in binder formulation.

These findings exhibit the critical role of polymer-modified bitumen in pavement engineering, demonstrating its ability to improve durability and mitigate rutting. SBS-modified mixtures enhance structural integrity under thermal stress, reducing susceptibility to deformation. Optimising binder composition and refining mixing protocols will strengthen pavement resilience, ensuring long-term performance in Kenya's evolving traffic and environmental conditions.

CONCLUSION

Several key conclusions can be drawn based on the study findings.

The commonly used penetration grade asphalt binders in Kenya—35/50, 50/70, 60/70, and 80/100—along with 60/70 modified with SBS, correspond to SUPERPAVE performance grades PG 82-22, PG 64-22, PG 76-22, PG 58-20, and PG 82-22, respectively.

SBS modification significantly enhances the performance of 60/70 penetration grade bitumen by improving elasticity, thermal stability, and overall durability. An optimal SBS concentration of 4.2% achieves a balance between stiffness and flexibility, making the binder particularly suitable for heavy traffic and extreme temperature conditions.

The tested aggregates comply with all relevant design standards, confirming their suitability for pavement construction. They exhibit high resistance to abrasion, crushing, and weathering.

The SUPERPAVE mix design method proves superior to the traditional Marshall design in key performance aspects. It enables optimised binder usage with a lower asphalt content (5.20% compared to Marshall's 5.88%), which can reduce material costs and the likelihood of binder-related distresses. Additionally, it offers higher Marshall stability and indirect tensile strength, enhancing load resistance and providing superior resistance to rutting, moisture damage, and temperature-induced distress.

Polymer-modified bitumen further improves rut resistance in SUPERPAVE hot mix asphalt (HMA), outperforming neat bitumen. Although neat HMA meets acceptable performance thresholds, certain variants show higher deformation under heavy traffic. SBS-modified mixtures perform better overall; however, minor inconsistencies in polymer dispersion suggest the need for further optimisation of the binder formulation.

RECOMMENDATIONS

To maximise the economic and functional benefits of SUPERPAVE, the following strategic approaches are recommended:

i) Develop comprehensive training programmes for engineers, technicians, and policymakers, focusing on SUPERPAVE principles, material characterisation, and performance-based testing methods. Integrate curriculum modules that emphasise the long-term cost benefits of durable, climate-adaptive pavement designs.

ii) Implement SUPERPAVE methodologies in select road sections under road agencies such as KeNHA, KeRRA, and KURA, monitoring performance over time. Use these pilot sites as case studies to demonstrate improvements in durability and cost savings, fostering stakeholder confidence.

iii) Conduct detailed cost-benefit analyses comparing initial construction expenses with long-term savings from reduced maintenance, repairs, and traffic disruptions. Advocate for funding mechanisms and policy incentives supporting advanced pavement design practices, emphasising financial sustainability.

iv) Develop Kenya-specific binder and aggregate selection standards based on SUPERPAVE's PG system, ensuring materials are optimised for local climatic conditions. Adapt laboratory testing protocols incorporating indigenous materials, facilitating broader acceptance and confidence in the methodology.

v) Enforce performance-based testing during material procurement and construction to ensure compliance with SUPERPAVE specifications. Utilise field performance feedback to refine design parameters and material selection, enhancing reliability and efficiency.

vi) Update national road design standards through the Ministry of Roads and Transport to integrate SUPERPAVE principles. Establish mandates or incentives for incorporating performance-based designs in new infrastructure projects.

vii) Emphasise that while initial costs may be higher due to sophisticated testing and materials, the extended pavement lifespan and reduced maintenance needs translate into substantial savings. Highlight SUPERPAVE's superior resilience against climate variability and heavy traffic, minimising costly damage and disruptions.

viii) Partner with international agencies, research institutions, and industry experts experienced in SUPERPAVE implementation to share best practices and technical expertise. Engage in knowledge exchange programmes, adapting global lessons to Kenya's infrastructure needs.

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APPENDIX A

Progress photos

Gunny bags stocked with fine and coarse aggregate samples

Sieve analysis for crushed limestone aggregates

Nominal representative sample aggregates used in the HMA mix designs

Riffled representative nominal aggregates used in the HMA mix designs

A drum of 60/70 penetration grade bitumen sample used in the mix designs

Evaluation of bitumen binder using penetration test at 25 ^{0}C

Manual pre-heating and mixing of measured aggregates and 60/70 penetration grade bitumen

Automatic Marshall compactor Equipment used in the Marshall compaction test

SUPERPAVE Gyratory Compactor equipment used in the SUPERPAVE compaction test

Setting up of HMA sample into the SUPERPAVE Gyratory mould

Double wheel tracker (EN12697-22) used in the Rut depth test

Ongoing test for Marshall stability and dial gauge reading

Ongoing test for Indirect tensile strength and dial gauge reading

SGC and Marshall compactor sample specimen

SUPERPAVE and Marshall sample specimens

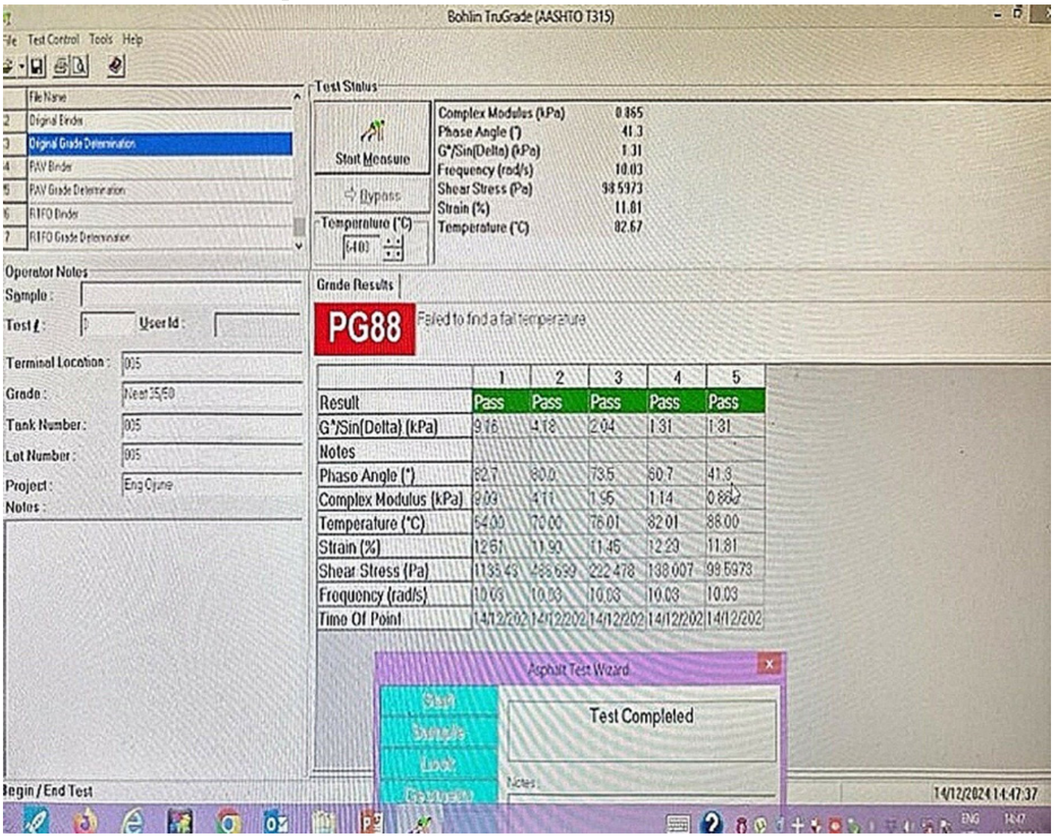
Compacted modified HMA in a rectangular slab, ready to be mounted on a double-wheel tracker for a rut depth test

Compacted neat HMA in a rectangular slab ready to be mounted on a double-wheel tracker for a rut depth test

Source: Field survey, 2025

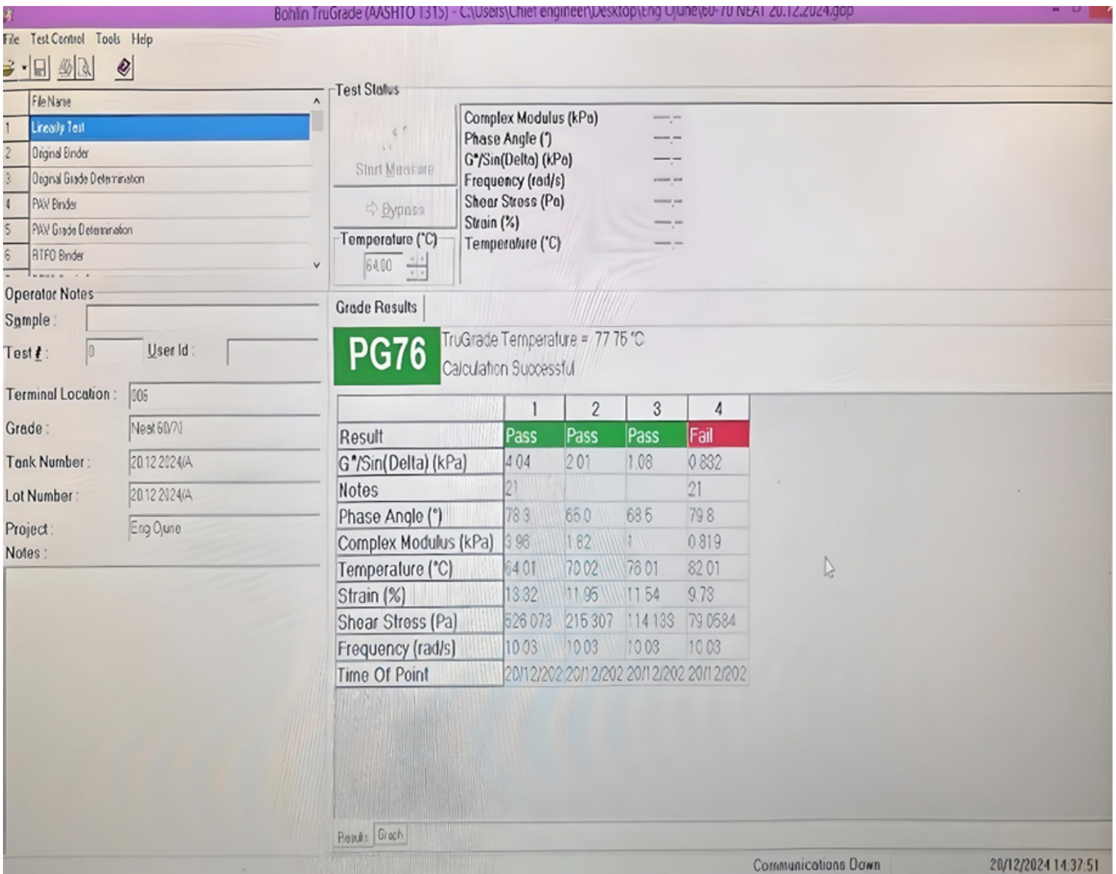
APPENDIX B

DSR test results for sampled neat bitumen binders & modified 60/70 bitumen binders with SBS



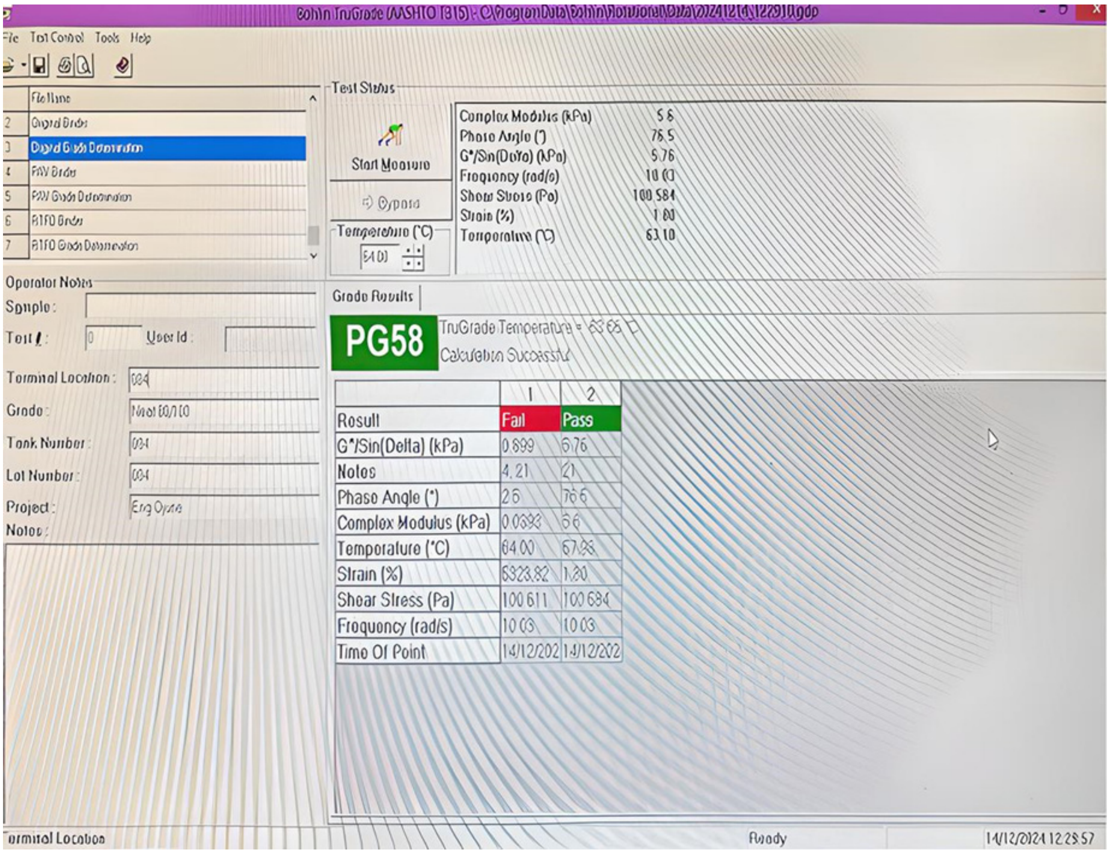
	1	2	3	4	5
Result	Pass	Pass	Pass	Pass	Pass
G*/Sin(Delta) (kPa)	9.16	4.18	2.04	1.31	1.31
Notes					
Phase Angle (°)	82.7	80.0	73.5	60.7	41.3
Complex Modulus (kPa)	9.03	4.11	1.95	1.14	0.865
Temperature (°C)	64.00	70.00	76.01	82.01	88.00
Strain (%)	12.61	11.90	11.45	12.29	11.81
Shear Stress (Pa)	1135.43	488.699	222.478	138.007	98.5973
Frequency (rad/s)	10.03	10.03	10.03	10.03	10.03
Time Of Point	14/12/202	14/12/202	14/12/202	14/12/202	14/12/202

Neat 35/50 equivalent to PG 82-22

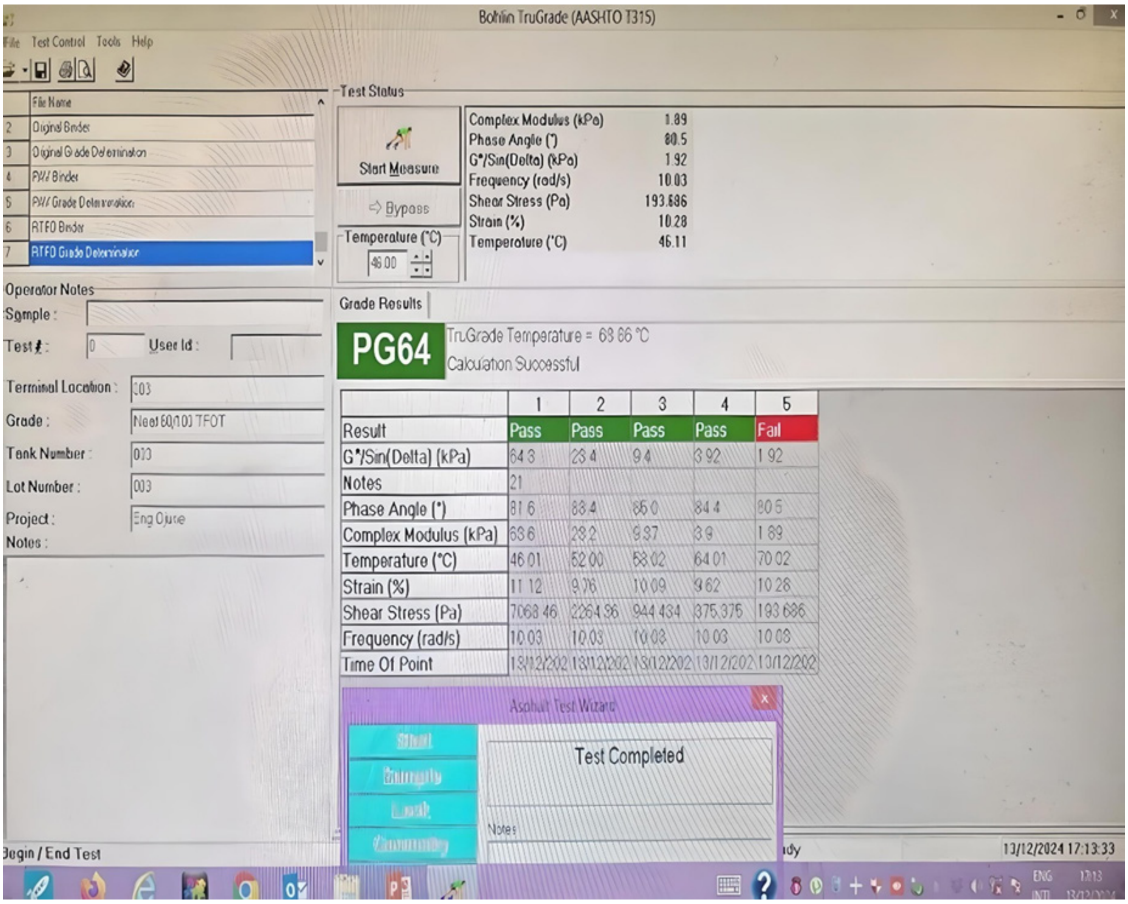


	1	2	3	4
Result	Pass	Pass	Pass	Fail
G*/Sin(Delta) (kPa)	4.04	2.01	1.08	0.832
Notes	21			21
Phase Angle (°)	78.3	65.0	68.5	79.8
Complex Modulus (kPa)	3.96	1.82	1	0.819
Temperature (°C)	64.01	70.02	76.01	82.01
Strain (%)	13.32	11.95	11.54	9.73
Shear Stress (Pa)	526.073	215.307	114.133	79.0584
Frequency (rad/s)	10.03	10.03	10.03	10.03
Time Of Point	20/12/202	20/12/202	20/12/202	20/12/202

Neat 60/70 equivalent to PG 76-22

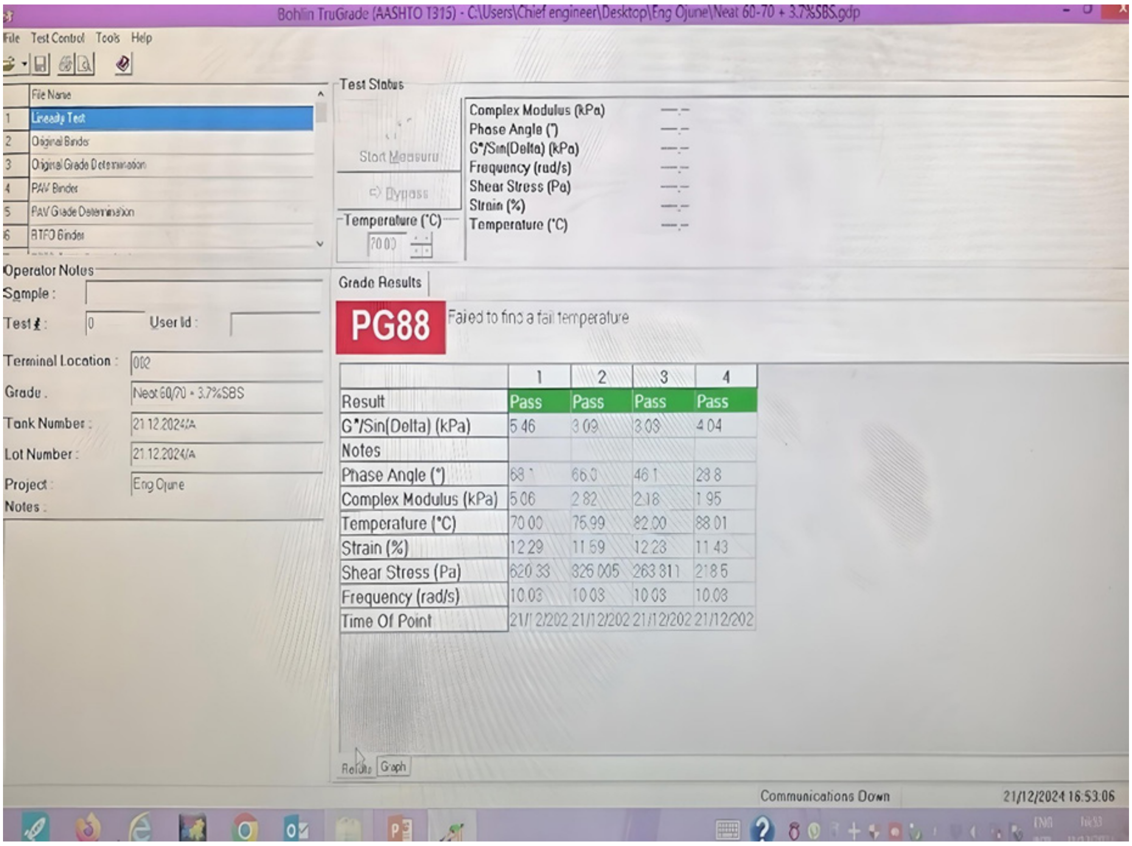


Neat 80/100 equivalent to PG 58-22

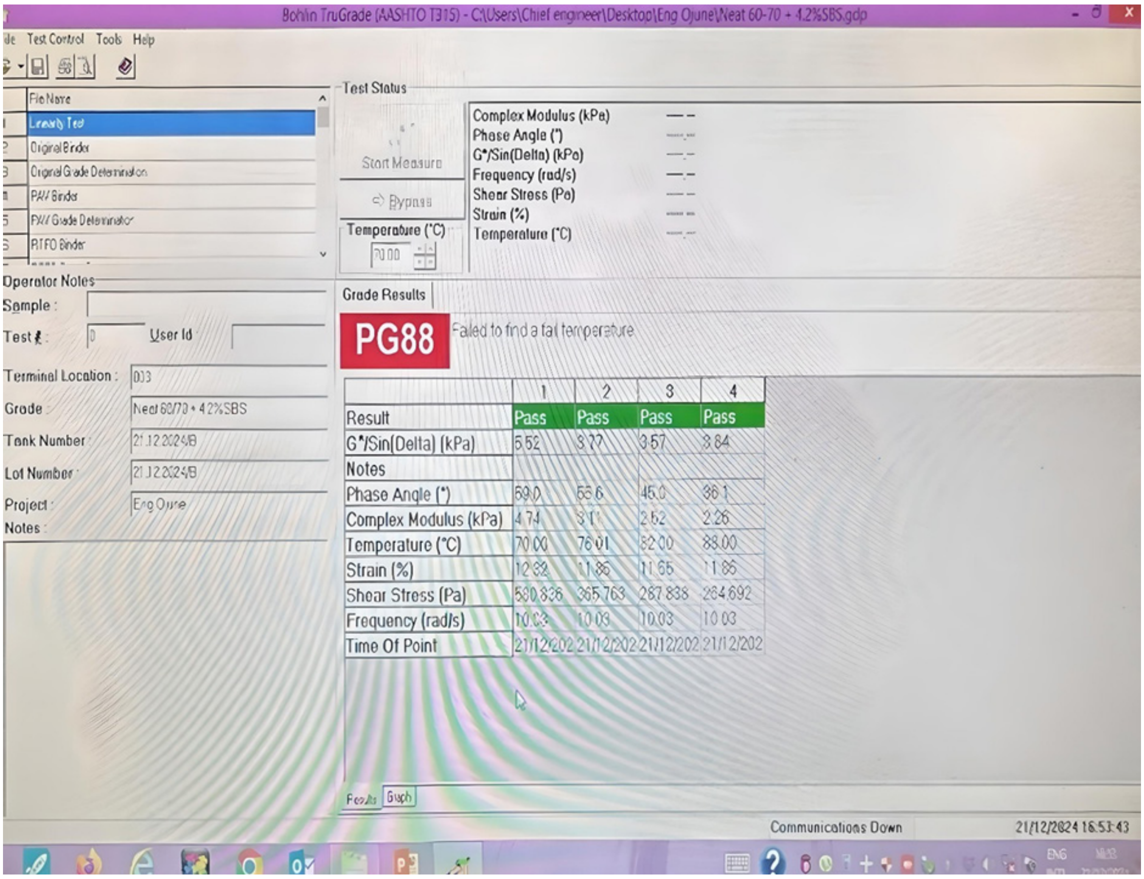


Neat 80/100 TFOT equivalent to PG 64-22

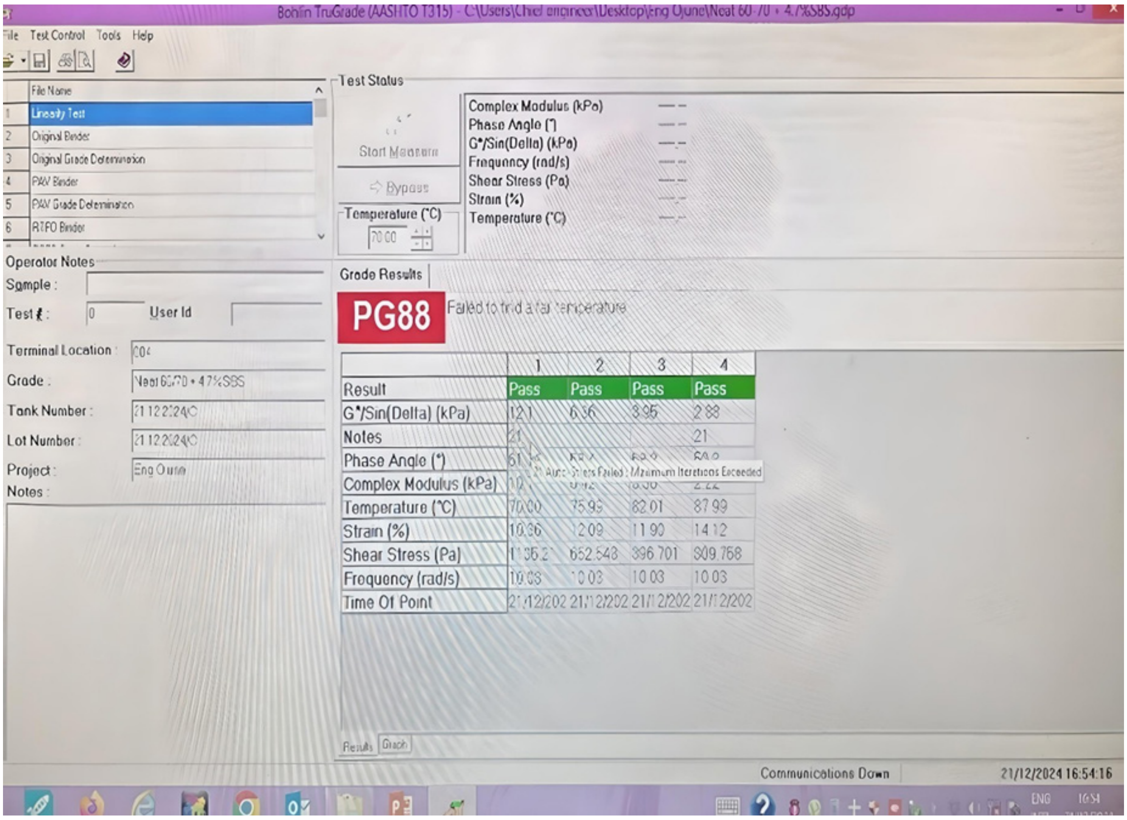
Source: Field surveys, 2025



Neat 60/70+3.7% SBS equivalent to PG 82-22



Neat 60/70+4.2% SBS equivalent to PG 82-22



Neat 60/70+4.7% SBS equivalent to PG 82-22
Source: Field survey, 2025

APPENDIX C

Grading of aggregates for Asphalt Concrete Wearing Course (ACWC) 0/20mm, Type 1, Binder Course

Aggregates single-size and combined grading									
Agg. size	**14/20 mm**	**10/14 mm**	**6/10 mm**	**0/6 mm**	**0/3 mm**	**Grading Requirements**			
Proportions used						Theoretical Curve	Actual grading	Std Spec for ACWC 0/20mm, Type I	
Sieve(mm)	**17%**	**13%**	**22%**	**7%**	**41%**			**Min**	**Max**
28	100	100	100	100	100	100		100	
20	98	100	100	100	100	100	100	90	100
14	17	98	100	100	100	86	99	75	95
10	1	8	93	99.5	99.5	69	84	60	82
6.3		26		100	100	51	66	47	68
4		2		89	90	43	51	37	58
2				70	72	34	39	25	43
1				45	50	24	27	18	32
0.425				22	29	13	17	11	22
0.3				17	24	11	14	9	17
0.15				10	17	8	10	5	12
0.075				6	11	5	6	3	7

Source: Kenya's (Standard Specifications for Road and Bridge Construction, MoR&PW, 1986)

APPENDIX D

Grading of aggregates for 19.0 mm NMS SUPERPAVE mix design

19.0 MM NMS MIX DESIGN													
Agg. Sizes (mm)	14/20	10/14	6/10	0/6	0/3	**Combined Theoretical Grading**	SUPERPAVE Specifications Control points as per Table 5.2 of (Asphalt Institute, 2014)						
Sieve Size (mm)	**Proportions**												
	18%	**18%**	**21%**	**43%**	**0%**		ASTM Sieves	Control points		Caution Zone			MDL
	Gradations							min	max	Sieve size	min	max	
25.0	100	100	100	100	100	100	25	100		2.36	34.6	35	100
19.0	95	100	100	100	100	99	19	90	100	1.18	22.3	28	95
12.5	2	74	100	100	100	78	12.5	-	90	0.6	16.7	21	79
9.5	-	3	84	100	100	61	9.5	56	80	0.3	13.7	14	68
4.75	-	-	2	95	95	41	4.75	35	65	PCS			50
2.36	-	-	1	67	71	29	2.36	23	49	Sieve	% passing		36
1.18	-	-	-	42	48	18	-	-	-	4.75	<47>		-
0.600	-	-	-	26	33	11	-	-	-	P 4.75 = 44<47%, hence a dense, coarse graded mix			-
0.300	-	-	-	16	22	7	0.30	5	19				12
0.150	-	-	-	10	15	4	-	-	-				-
0.075	-	-	-	6	11	3	0.075	2	8				5
MLD* - Minimum Design Level, PCS* - Percent Passing Control Sieve													

Source: Asphalt Institute, 2014

APPENDIX E

Determination of Combined Specific Gravity, Water Absorption and Max. Specific Gravity for Aggregates for Marshall & SUPERPAVE Method: Volumetric calculations

The following volumetric nomenclature and test method were used in HMA designs for Marshall and SUPERPAVE, as adopted from Table 5.1, page 15 of (ORN 19, Design of Hot Mix Asphalt, 2002).

TABLE 1

Volumetric nomenclature and test methods

Volumetric nomenclature and test methods				
Component	**Volumetric description**	**Nomenclature**	**ASTM**	**AASHTO**
Constituents	Bulk Specific Gravity of coarse aggregate	Gca	C127	T85
	Bulk Specific Gravity of fine aggregate	Gfa	C128	T84
	Bulk Specific Gravity of mineral filler	Gf	D854	T100
	Bulk Specific Gravity of total aggregate	Gsb		
	Bulk Specific Gravity of Bitumen	Gb	D70	T228

Component	Volumetric description	Nomenclature	ASTM	AASHTO
Mixed material	Bulk Specific Gravity of compacted material	Gmb	D2726	T166
	Maximum Specific Gravity of loose material	Gmm	D2041	T209
	Air voids	VIM	D3203	T269
	Effective bitumen content	Pbe		
	Voids in mineral aggregate	VMA		
	Voids filled with bitumen	VFB		

Source: Field survey, 2025

TABLE 2
Determination of Specific Gravity for Coarse Aggregates

Specific Gravity Determination of Coarse Aggregates as Per AASHTO T85								
	Aggregate size	**14/20 mm**		**10/14 mm**		**6/10 mm**		
	Test No.	1	2	1	2	1	2	
A	Wt. of an oven-dried sample (g)	225	211	238	203	186	233	
B	Saturated Surface Dry (SSD) Wt. in air (g)	231	217	244	208	192	240	
C	Wt. of saturated sample in water	140	131	149	127	117	146	
Calculations								**Acceptable Range of 2 Results**
B.S.G (Oven based) = A/ (B - C)		2.473	2.453	2.505	2.506	2.480	2.479	0.025
Average BSG (Oven)		**2.463**		**2.506**		**2.479**		
B.S.G (Apparent) = A/ (A - C)		2.647	2.638	2.674	2.671	2.696	2.678	0.02
Average BSG (Apparent)		**2.642**		**2.673**		**2.687**		
Sp. Gr. (SSD Based) = B/ (B - C)		2.538	2.523	2.568	2.568	2.560	2.553	
Average Specific Gravity		**2.531**		**2.568**		**2.557**		
Water Absorption = 100*(B-A)/A		2.667	2.844	2.521	2.463	3.226	3.004	0.25
Average Water Absorption of Coarse Aggregates		**2.8**		**2.5**		**3.1**		

Source: Field survey, 2025

TABLE 3
Determination of Specific Gravity for Fine Aggregates

Specific Gravity Determination of Fine Aggregates as Per AASHTO T84						
	Aggregate size	**0/6 mm**		**0/3 mm**		
	Test No.	1	2	1	2	
	Mass of Pycnometer + water (g)	2360.5	2360.5	2110.0	2110.0	
	Mass of Pycnometer +Sample + Water (g)	2635.5	2546.5	2182.0	2187.0	
A	Oven Dry mass of the sample (g)	437	298	116	122	
B	Apparent weight	275.0	186.0	72.0	77.0	
C	SSD Sample	450	306	120	126	
Calculations						**Acceptable Range of 2 Results**
B.S.G (Oven based) = A/ (C - B)		2.497	2.483	2.417	2.490	0.032
Average BSG (Oven)		**2.490**		**2.453**		
B.S.G (Apparent) = A/ (A - B)		2.698	2.661	2.636	2.711	0.027
Average BSG (Apparent)		**2.679**		**2.674**		
Sp. Gr. (SSD Based) = C/ (C - B)		**2.571**	**2.550**	**2.500**	**2.571**	
Average Specific Gravity		**2.561**		**2.536**		
Water Absorption = 100*(C-A)/A		2.975	2.685	3.448	3.279	0.31
Average Water Absorption of Fine Aggregates		**2.8**		**3.4**		

Source: Field survey, 2025

TABLE 4
Combined Sp. Gr. & Water Absorption of Aggregates (Marshall method)

Aggregate Specific Gravity				
Aggregate size (mm)	Fraction in the mix for the Marshall Method	Bulk Spec. Gravity (Oven)	App. Sp. Gr.	WA of Aggregates
14/20	17 (P1)	2.463 (G1)	2.642	2.8
10/14mm	13 (P2)	2.506 (G2)	2.673	2.5
6/10mm	22 (P3)	2.479 (G3)	2.687	3.1
0/6mm	7 (P4)	2.490 (G4)	2.679	2.8
0/3mm	41 (P5)	2.453 (G5)	2.674	3.4
Combined Sp. Gr. & Water absorption of Aggregates		**2.470**	**2.672**	**3.04**
		Gsb	**Gsa**	**WA**

Source: Field survey, 2025

Bulk Specific Gravity of total aggregate (Gsb): Substituting the data from Table 4 above into Equation 5.

$$Gsb = \frac{P1+P2+P3+P4+P5}{\frac{P1}{G1}+\frac{P2}{G2}+\frac{P3}{G3}+\frac{P4}{G4}+\frac{P5}{G5}}$$

Where, Gsb = bulk specific gravity for the total aggregate. P1, P2... P5 = individual percentages by weight of aggregates. G1, G2... G5 = individual bulk specific gravities of aggregates.

$$Gsb = \frac{17+13+22+7+41}{\frac{17}{2.463}+\frac{13}{2.506}+\frac{22}{2.479}+\frac{7}{2.490}+\frac{14}{2.453}} = 2.470 \text{ (Table 4)}$$

A similar formula was used in the determination of Gsa

Combined Sp. Gr. of Aggregates (Gsb) Oven Dry Basis	**2.470**
Combined Apparent Sp. Gr. of Aggregates (Gsa)	**2.672**
Effective Sp. Gr. of Aggregates (Gse)	**2.549**

Source: Field survey, 2025

TABLE 5
Maximum Specific Aggregates (Marshall & SUPERPAVE)

Max.Sp.Gr			
60/70 Penetration Grade Bitumen	**4.2%**	**4.7%**	**5.2%**
Wt sample	515	511	424
PY In H2O	100	102	286.5
PY+Sample in H2O	401.5	398.0	530.5
Max. Specific Gravity of loose material, Gmm	2.412	2.377	2.356
Effective specific gravity of aggregate, Gse	2.566	2.544	2.538
Average Gse	**2.549**		

Source: Field survey, 2025

TABLE 6
Combined Sp. Gr. & Water Absorption of Aggregates (SUPERPAVE METHOD)

Aggregate Specific Gravity				
Aggregate size (mm)	Fraction in mix for SUPERPAVE	Bulk Spec. Gravity (Oven)	App. Sp. Gr.	WA of Aggregates
14/20	18 (P1)	2.463 (G1)	2.642	2.8
10/14mm	18 (P2)	2.506 (G2)	2.673	2.5
6/10mm	21 (P3)	2.479 (G3)	2.687	3.1
0/6mm	43 (P4)	2.490 (G4)	2.679	2.8
Combined Sp. Gr. & Water absorption of Aggregates		**2.486**	**2.670**	**2.8**
		Gsb	**Gsa**	**WA**

Source: Field survey, 2025

$$Gsb = \frac{18+18+21+43}{\frac{18}{2.463}+\frac{18}{2.506}+\frac{21}{2.479}+\frac{43}{2.490}} = 2.486 \text{ (Table 6)}$$

A similar formula was used in the determination of Gsa

Combined Sp. Gr. of Aggregates (Gsb) Oven Dry Basis	**2.486**
Combined Apparent Sp. Gr. of Aggregates (Gsa)	**2.670**
Effective Sp. Gr. of Aggregates (Gse)	**2.549**

Source: Field survey, 2025

The average Gse of 2.549 was used in Marshall and SUPERPAVE mixed material volumetric calculations since the same aggregate source was used.

ITS and Stability Calculations
To calculate the percentage increase in ITS when SBS is incorporated, we use the formula:

$$Percentage\ Increase = \frac{ITS\ with\ SBS - ITS\ without\ SBS}{ITS\ without\ SBS}\ x\ 100\%$$

Equation 1

Applying this to data from Figures 8 and 9:

Initial ITS:

- SUPERPAVE:

$$\frac{912-943}{943}\ x\ 100\% = -3.29\%\ \text{(A slight decrease)}$$

- Marshall:

$$\frac{780-870}{870}\ x\ 100\% = -10.34\%\ \text{(A decrease)}$$

Conditioned ITS:

- SUPERPAVE:
$$\frac{846-851}{851}\ x\ 100\% = -0.59\%\ \text{(A slight decrease)}$$
- Marshall:
$$\frac{664-769}{769}\ x\ 100\% = -13.66\%\ \text{(A decrease)}$$

To calculate the percentage increase in stability when SBS is incorporated, we use the formula:

$$Percentage\ Increase = \frac{Stability\ with\ SBS - Stability\ without\ SBS}{Stability\ without\ SBS}\ x\ 100\% \qquad Equation\ 2$$

Applying this to data from Figures 10 and 11:

Initial Stability Increase

- **SUPERPAVE**
$$\frac{20{,}148-16{,}933}{16{,}933}\ x\ 100\% = 18.97\%\ \text{(Significant increase)}$$
- **Marshall**
$$\frac{16{,}252-15{,}028}{15{,}028}\ x\ 100\% = 8.14\%\ \text{(Moderate increase)}$$

Conditioned Stability Increase

- **SUPERPAVE**
$$\frac{16{,}778-15{,}692}{15{,}692}\ x\ 100\% = 6.92\%\ \text{(Slight increase)}$$
- **Marshall**
$$\frac{12{,}575-14{,}540}{14{,}540}\ x\ 100\% = -13.50\%\ \text{(Decrease)}$$

The preceding appendices (F, G, H, and I) contain formulas and detailed test results for the HMA specimens obtained by the Marshall and SUPERPAVE methods, calculated using Excel spreadsheets.

APPENDIX F

Detailed observations and results of the Marshall design for the AC Trial

The detailed calculations for the Marshall trial mix were guided by (ORN 19, Design of Hot Mix Asphalt, 2002) and (Asphalt Institute, 2014).

Marshall Compaction			75 Blows			Grade Bitumen				60/70			Project	Msc Civil Eng.		
Specific Gravity of Bitumen, **Gb**			1.02			Absorbed AC of Aggregate							Location	MTRD, Nairobi		
Bulk S.G Aggregate, **Gsb**			2.47			Effective S.G. Aggregates, **Gse**				2.549	0	0	Date	Dec, 2024		
		Mass, grams										Stability				
% Bitumen by wt. of mix, Pb	**Spec. No.**	**In Air**	**In Water**	**Sat. Surface Dry In Air**	**Bulk Volume, cc**	**Bulk S.G. Specimen**	**Max. S.G. (Loose Mix)**	**% VIM**	**%VMA**	**%VFB**	**Reading, N**	**Ring Factor**	**Normal Stability, kN**	**Vol. Correction Ratio**	**Corrected Stability, kN**	**Flow (0.25 mm)**
						Gmb	**Gmm**									
a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**
					e-d	c/(f)	100/{(Ps/Gse)+(Ps/Gb)}	100*{(Gmm-Gmb)/Gmm}	100-(Gmb*Ps/Gsb)	100*{(VMA-VIM)/VMA}			n*o		p*q	
4.2	A	1144	630	1154	524	2.183	2.398				1000	0.0125	12.5	0.96	12.0	2.5
4.2	B	1160	642	1168	526	2.205	2.398				1110	0.0125	13.9	0.96	13.3	3.0
4.2	C	1136	631	1146	515	2.206	2.398				1400	0.0125	17.5	1.25	21.9	2.0
Average						**2.198**	**2.398**	8.3	14.7	43.5	**1170**				**15.7**	**2.5**
4.7	A	1129	630	1137	507	2.227	2.381				980	0.0125	12.3	1.04	12.7	2.7
4.7	B	1132	633	1134	501	2.259	2.381				1160	0.0125	14.5	1.04	15.1	2.5
4.7	C	1148	642	1150	508	2.260	2.381				1580	0.0125	19.8	1.04	20.5	3.1
Average						**2.249**	**2.381**	5.6	13.2	57.9	**1240**				**16.1**	**2.8**
5.2	A	1145	632	1151	519	2.206	2.365				945	0.0125	11.8	1.00	11.8	2.0
5.2	B	1149	584	1154	570	2.016	2.365				1080	0.0125	13.5	0.86	11.6	2.2
5.2	C	1040	579	1044	465	2.237	2.365				850	0.0125	10.6	1.19	12.6	2.1
Average						**2.221**	**2.365**	6.1	14.7	58.9	**958**				**12.0**	**2.1**
5.7	A	1142	634	1146	512	2.230	2.348				945	0.0125	11.8	1.00	11.8	2.3
5.7	B	1141	636	1142	506	2.255	2.348				1050	0.0125	13.1	1.04	13.7	2.4
5.7	C	1141	636	1143	507	2.250	2.348				850	0.0125	10.6	1.04	11.1	3.2
Average						**2.245**	**2.348**	4.4	14.3	69.3	**948**				**12.2**	**2.6**
6.2	A	1150	646	1152	506	2.273	2.332				1060	0.0125	13.3	1.04	13.8	2.6
6.2	B	1136	632	1137	505	2.250	2.332				865	0.0125	10.8	1.04	11.2	3.0
6.2	C	1144	636	1146	510	2.243	2.332				750	0.0125	9.4	1.00	9.4	3.1
Average						**2.255**	**2.332**	3.3	14.4	77.0	**892**				**11.5**	**2.9**

Source: Field survey, 2025

APPENDIX G

Detailed observations and results of the SUPERPAVE design for the AC Trials

SUPERPAVE GYRATORY METHOD VOLUMETRIC PROPERTIES TEST REPORT BY EN 12697 - 31

Pb - **A**	Max. Sp. Gr. (**D**)	Gse (**Q**)	Gsb (**R**)	P_{be} (**U**)	P_{ba} (**T**)	Spec Dia-- **B**	$P_{0.075}$ (**S**)
4.2	2.398	2.549	2.486	3.229	1.014	100	3.0

Specimen #	4.2B			Wt taken(g) - **C**			1890.0				Averaged Values					
Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio	**Corrected Bulk Density**	**%Gmm**	**Va**	**VMA**	**VFB**	**Dust/Pbe Ratio**
No.	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)		g/cm^3	(%)	(%)	(%)	(%)	
	E	$F=3.14*B^2*E/(4*1000)$	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U						
8	129.6	1017.4	1.858	1.07	1.988	82.9	17.1	23.4	26.9	0.9	1.988	82.9	17.1	23.4	26.9	0.9
9	129.0	1012.7	1.866	1.07	1.998	83.3	16.7	23.0	27.5	0.9	1.998	83.3	16.7	23.0	27.5	0.9
10	128.4	1007.9	1.875	1.07	2.007	83.7	16.3	22.7	28.0	0.9	2.007	83.7	16.3	22.7	28.0	0.9
60	119.7	939.6	2.011	1.07	2.153	89.8	10.2	17.0	40.0	0.9	2.153	89.8	10.2	17.0	40.0	0.9
80	118.6	931.0	2.030	1.07	2.173	90.6	9.4	16.3	42.3	0.9	2.173	90.6	9.4	16.3	42.3	0.9
100	117.7	923.9	2.046	1.07	2.190	91.3	8.7	15.6	44.4	0.9	2.190	91.3	8.7	15.6	44.4	0.9
125	116.9	917.7	2.060	1.07	2.205	91.9	8.1	15.0	46.4	0.9	2.205	91.9	8.1	15.0	46.4	0.9
205	115.1	903.5	2.092	1.07	2.239	93.4	6.6	13.7	51.7	0.9	2.239	93.4	6.6	13.7	51.7	0.9

Geometric Density at N_{design}	2.092	
Actual Density at N_{design}	2.239	
Correction Factor **H** =	Actual Bulk Density/at N_{design} Geometric Density at N_{design}	1.07

Source: Field survey, 2025

SUPERPAVE GYRATORY METHOD VOLUMETRIC PROPERTIES TEST REPORT BY EN 12697 - 31

Pb - **A**	Max. Sp. Gr. (**D**)	Gse (**Q**)	Gsb (**R**)	P_{be} (U)	P_{ba} (T)	Spec Dia--**B**	$P_{0.075}$ (**S**)
4.7	2.381	2.549	2.486	3.734	1.014	100	3.0

Specimen # 4.7A — Wt taken(g) - **C**: 1880.0

Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio
	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)	
	E	F=3.14*B²*E/(4*1000)	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U
8	127.1	997.7	1.884	1.06	2.006	84.3	15.7	23.1	31.8	0.8
9	126.4	992.2	1.895	1.06	2.018	84.7	15.3	22.7	32.6	0.8
10	125.8	987.5	1.904	1.06	2.027	85.1	14.9	22.3	33.3	0.8
60	116.5	914.5	2.056	1.06	2.189	91.9	8.1	16.1	49.8	0.8
80	115.2	904.3	2.079	1.06	2.214	93.0	7.0	15.1	53.5	0.8
100	114.3	897.3	2.095	1.06	2.231	93.7	6.3	14.5	56.4	0.8
125	113.5	891.0	2.110	1.06	2.247	94.4	5.6	13.9	59.3	0.8
205	111.8	877.6	2.142	1.06	2.281	95.8	4.2	12.6	66.5	0.8

Geometric Density at N_{design}: 2.142
Actual Density at N_{design}: 2.281
Correction Factor **H** = Actual Bulk Density/at N_{design} Geometric Density at N_{design}: 1.06

Specimen # 4.7B — Wt taken(g) - **C**: 1880.0

Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio
	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)	
	E	F=3.14*B²*E/(4*1000)	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U
8	126.7	994.6	1.890	1.07	2.014	84.6	15.4	22.8	32.3	0.8
9	126.0	989.1	1.901	1.07	2.025	85.0	15.0	22.4	33.1	0.8
10	125.4	984.4	1.910	1.07	2.035	85.4	14.6	22.0	33.8	0.8
60	116.5	914.5	2.056	1.07	2.190	92.0	8.0	16.0	49.9	0.8
80	115.2	904.3	2.079	1.07	2.215	93.0	7.0	15.1	53.7	0.8
100	114.3	897.3	2.095	1.07	2.232	93.7	6.3	14.4	56.6	0.8
125	113.5	891.0	2.110	1.07	2.248	94.4	5.6	13.8	59.5	0.8
205	111.8	877.6	2.142	1.07	2.282	95.8	4.2	12.5	66.7	0.8

Geometric Density at N_{design}: 2.142
Actual Density at N_{design}: 2.282
Correction Factor **H** = Actual Bulk Density/at N_{design} Geometric Density at N_{design}: 1.07

Averaged Values

Gyrations/cycles	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio
	g/cm^3	(%)	(%)	(%)	(%)	
8	2.010	84.4	15.6	22.9	32.1	0.8
9	2.021	84.9	15.1	22.5	32.9	0.8
10	2.031	85.3	14.7	22.1	33.6	0.8
60	2.189	91.9	8.1	16.1	49.9	0.8
80	2.214	93.0	7.0	15.1	53.6	0.8
100	2.232	93.7	6.3	14.5	56.5	0.8
125	2.247	94.4	5.6	13.8	59.4	0.8
205	2.282	95.8	4.2	12.5	66.6	0.8

Source: Field survey, 2025

SUPERPAVE GYRATORY METHOD VOLUMETRIC PROPERTIES TEST REPORT BY EN 12697 - 31

Pb - **A**	5.2	Max. Sp. Gr. (**D**)	2.365	Gse (**Q**)	2.549	Gsb (**R**)	2.486	P_{be} (U)	4.239	P_{ba} (T)	1.014	**Spec Dia--B**	100	$P_{0.075}$(**S**)	3.0

Specimen #	5.2A			Wt taken(g) - **C**			1940.0				**Averaged Values**					
Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio	**Corrected Bulk Density**	**%Gmm**	**Va**	**VMA**	**VFB**	**Dust/Pbe Ratio**
	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)		**g/cm^3**	**(%)**	**(%)**	**(%)**	**(%)**	
	E	F=3.14*B²*E/(4*1000)	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U						
8	128.8	1011.1	1.919	1.06	2.028	85.7	14.3	22.7	37.1	0.7	2.028	85.7	14.3	22.7	37.1	0.7
9	128.1	1005.6	1.929	1.06	2.039	86.2	13.8	22.3	38.1	0.7	2.039	86.2	13.8	22.3	38.1	0.7
10	127.4	1000.1	1.940	1.06	2.050	86.7	13.3	21.8	39.0	0.7	2.050	86.7	13.3	21.8	39.0	0.7
60	117.9	925.5	2.096	1.06	2.215	93.7	6.3	15.5	59.3	0.7	2.215	93.7	6.3	15.5	59.3	0.7
80	116.6	915.3	2.120	1.06	2.240	94.7	5.3	14.6	63.8	0.7	2.240	94.7	5.3	14.6	63.8	0.7
100	115.7	908.2	2.136	1.06	2.257	95.5	4.5	13.9	67.3	0.7	2.257	95.5	4.5	13.9	67.3	0.7
125	114.9	902.0	2.151	1.06	2.273	96.1	3.9	13.3	70.9	0.7	2.273	96.1	3.9	13.3	70.9	0.7
205	113.2	888.6	2.183	1.06	2.307	97.6	2.4	12.0	79.7	0.7	2.307	97.6	2.4	12.0	79.7	0.7

Geometric Density at N_{design}	2.183	
Actual Density at N_{design}	2.307	
Correction Factor **H** =	Actual Bulk Density/at N_{design} Geometric Density at N_{design}	1.06

Source: Field survey, 2025

SUPERPAVE GYRATORY METHOD VOLUMETRIC PROPERTIES TEST REPORT BY EN 12697 - 31

Pb - A	5.7	Max. Sp. Gr. (**D**)	2.348	Gse (**Q**)	2.549	Gsb (**R**)	2.486	P_{be} (U)	4.744	P_{ba} (T)	1.014	**Spec Dia--B**	100	$P_{0.075}$(**S**)	3.0

Specimen #	5.7A			Wt taken(g) - **C**			2000.0				Averaged Values					
Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio	**Corrected Bulk Density**	**%Gmm**	**Va**	**VMA**	**VFB**	**Dust/Pbe Ratio**
	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)		**g/cm^3**	**(%)**	**(%)**	**(%)**	**(%)**	
	E	F=3.14*B²*E/(4*1000)	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U						
8	133.0	1044.1	1.916	1.06	2.030	86.5	13.5	23.0	41.1	0.6	2.030	86.5	13.5	23.0	41.1	0.6
9	132.2	1037.8	1.927	1.06	2.043	87.0	13.0	22.5	42.2	0.6	2.043	87.0	13.0	22.5	42.2	0.6
10	131.5	1032.3	1.937	1.06	2.054	87.4	12.6	22.1	43.2	0.6	2.054	87.4	12.6	22.1	43.2	0.6
60	121.5	953.8	2.097	1.06	2.223	94.6	5.4	15.7	65.9	0.6	2.223	94.6	5.4	15.7	65.9	0.6
80	120.1	942.8	2.121	1.06	2.249	95.7	4.3	14.7	71.1	0.6	2.249	95.7	4.3	14.7	71.1	0.6
100	119.2	935.7	2.137	1.06	2.265	96.5	3.5	14.1	74.9	0.6	2.265	96.5	3.5	14.1	74.9	0.6
125	118.3	928.7	2.154	1.06	2.283	97.2	2.8	13.4	79.2	0.6	2.283	97.2	2.8	13.4	79.2	0.6
205	116.5	914.5	2.187	1.06	2.318	98.7	1.3	12.1	89.3	0.6	2.318	98.7	1.3	12.1	89.3	0.6

Geometric Density at N_{design}	2.187
Actual Density at N_{design}	2.318
Correction Factor **H** = Actual Bulk Density/at N_{design} Geometric Density at N_{design}	1.06

Source: Field survey, 2025

SUPERPAVE GYRATORY METHOD VOLUMETRIC PROPERTIES TEST REPORT BY EN 12697 - 31

Pb - **A**	6.2	Max. Sp. Gr. (**D**)	2.332	Gse (**Q**)	2.549	Gsb (**R**)	2.486	P_{be} (U)	5.249	P_{ba} (T)	1.014	**Spec Dia--B**	100	$P_{0.075}$(**S**)	3.0

Specimen # 6.2A — Wt taken(g) - **C** 2000.0

Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio
	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)	
	E	F=3.14*B²*E/(4*1000)	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U
8	131.0	1028.4	1.945	1.05	2.043	87.6	12.4	22.9	45.9	0.6
9	130.2	1022.1	1.957	1.05	2.055	88.1	11.9	22.4	47.1	0.6
10	129.6	1017.4	1.966	1.05	2.065	88.5	11.5	22.1	48.1	0.6
60	119.7	939.6	2.128	1.05	2.236	95.9	4.1	15.6	73.5	0.6
80	118.4	929.4	2.152	1.05	2.260	96.9	3.1	14.7	79.0	0.6
100	117.5	922.4	2.168	1.05	2.278	97.7	2.3	14.1	83.3	0.6
125	116.7	916.1	2.183	1.05	2.293	98.3	1.7	13.5	87.6	0.6
205	115.3	905.1	2.210	1.05	2.321	99.5	0.5	12.4	96.1	0.6

Geometric Density at N_{design} 2.210

Actual Density at N_{design} 2.321

Correction Factor **H** = Actual Bulk Density/at N_{design} Geometric Density at N_{design} 1.05

Specimen # 6.2B — Wt taken(g) - **C** 2000.0

Gyrations/cycles	Height	Volume	Geometric Density	Correction Factor	Corrected Bulk Density	%Gmm	Va	VMA	VFB	Dust/Pbe Ratio
	(mm)	cm^3	g/cm^3		g/cm^3	(%)	(%)	(%)	(%)	
	E	F=3.14*B²*E/(4*1000)	G=C/F	H	J = G*H	K=100*J/D	L=100-K	M = 100-(J*(100-A)/R	N= 100*(M-L)/M	P= S/U
8	129.4	1015.8	1.969	1.04	2.053	88.0	12.0	19.4	38.1	0.6
9	128.7	1010.3	1.980	1.04	2.064	88.5	11.5	18.9	39.2	0.6
10	128.1	1005.6	1.989	1.04	2.074	88.9	11.1	18.5	40.2	0.6
60	118.8	932.6	2.145	1.04	2.236	95.9	4.1	12.2	66.0	0.6
80	117.6	923.2	2.166	1.04	2.259	96.9	3.1	11.3	72.0	0.6
100	116.7	916.1	2.183	1.04	2.276	97.6	2.4	10.6	77.3	0.6
125	115.9	909.8	2.198	1.04	2.292	98.3	1.7	10.0	82.6	0.6
205	114.4	898.0	2.227	1.04	2.322	99.6	0.4	8.8	95.0	0.6

Geometric Density at N_{design} 2.227

Actual Density at N_{design} 2.322

Correction Factor **H** = Actual Bulk Density/at N_{design} Geometric Density at N_{design} 1.04

Averaged Values

Gyrations/cycles	**Corrected Bulk Density**	**%Gmm**	**Va**	**VMA**	**VFB**	**Dust/Pbe Ratio**
	g/cm^3	(%)	(%)	(%)	(%)	
8	2.047834486	87.8	12.2	21.136	41.97	0.572
9	2.059693164	88.3	11.7	20.680	43.15	0.572
10	2.069284727	88.7	11.3	20.310	44.14	0.572
60	2.235841688	95.9	4.1	13.899	69.79	0.572
80	2.25952345	96.9	3.1	12.988	75.53	0.572
100	2.276889741	97.6	2.4	12.319	80.31	0.572
125	2.292552093	98.3	1.7	11.716	85.10	0.572
205	2.3215	99.5	0.5	10.600	95.56	0.572

Source: Field survey, 2025

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APPENDIX H

ITS and Loss of ITS (AASHTO T283) Test Results

1

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -AASHTO T283

CLIENT'S NAME: Eng. N.O. Parapara
PROJECT NAME: Thesis project for Master of science in civil Engineering
JOB DESCRIPTION: SUPERPAVE specimen moulded at 205 Gyrations (Neat)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade bitumen.
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE: Aggregates from Katani Quarry in Machakos County & Bitumen from Local supplier
DATE TESTED: 11/02/2025 LABORATORY:

ITS TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET 1ST SET				CONDITIONED SET 2ND SET				AVERAGE	REMARKS
Sample ID		N1	N2	N3	N4	N5	N6	N7	N8		
Diameter, mm	Dia	100	100	100	100	100	100	100	100		
Sample Height, mm	Ht	67.170	65.694	65.662	65.000	65.703	65.493	66.367	66.081		
Wt. in air, g	A	1085	1049	1050	1048	1050	1048	1056	1054		
Wt. in water, g	B	607	586	587	590	589	589	593	593		
SSD Wt., g	C	1088	1054	1055	1052	1055	1053	1063	1061		
Volume, cm3	D=C - B	481	468	468	462	466	464	470	468		
Water Absorption	E=100*[(C-A)/D]	0.62	1.07	1.07	0.87	1.07	1.08	1.49	1.50		
Bulk Spec. Gravity, Gmb	F= A/D	2.256	2.241	2.244	2.268	2.253	2.259	2.247	2.252		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	5.262	5.861	5.771	4.729	5.367	5.140	5.636	5.412	5.406	6' - 8
Maximum Load, kN	K	10.007	7.065	10.559	8.733	7.856	8.607	7.241	9.903		
ITS (Dry), kPa	L = (2*K*1,000,000)/(3.142*Ht*Dia)	949	687	1024	856					879	
ITS (Wet) kPa	M = (2*K*1,000,000)/(3.142*Ht*Dia)					762	837	695	955	812	
Tensile Strenght Ratio (TSR)%	N = 100*M/L									92.4	≥80%
ITS Loss (%)	N-100%									7.6	≤20%

Tested by: Margrate Mbele Checked by: Eng. N.O. Parapara
Date: 11/02/2025 Date: 11/02/2025

Source: Field survey, 2025

2

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -AASHTO T283

CLIENT'S NAME: Eng N.O. Parapara
PROJECT NAME: Thesis project for Master of science in civil Engineering
JOB DESCRIPTION: Marshall specimen moulded at 75 blows (Neat)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade Bitumen
DATE RECEIVED: 08/12/2024
MATERIAL SOURCE: Aggregates from Katani quarry in Mlolongo & Bitumen from Local supplier
DATE TESTED: 18/02/2025 LABORATORY:

ITS TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET 1ST SET				CONDITIONED SET 2ND SET				AVERAGE	REMARKS
Sample ID		N9	N10	N11	N12	N13	N14	N15	N16		
Diameter, mm	Dia	101	101	101	101	101	101	101	101		
Sample Height, mm	Ht	64	63	65	65	64	64	63	63		
Wt. in air, g	A	1136	1130	1135	1137	1137	1143	1143	1142		
Wt. in water, g	B	639	634	633	635	634	639	643	639		
SSD Wt., g	C	1141	1132	1138	1141	1141	1146	1146	1144		
Volume, cm3	D=C - B	502	498	505	506	507	507	503	505		
Water Absorption	E=100*[(C-A)/D]	1.00	0.40	0.59	0.79	0.79	0.59	0.60	0.40		
Bulk Spec. Gravity, Gmb	F= A/D	2.263	2.269	2.248	2.247	2.243	2.254	2.272	2.261		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	4.958	4.701	5.606	5.626	5.813	5.316	4.563	5.024	5.201	6' - 8
Maximum Load, kN	K	9.735	8.306	9.455	8.888	7.807	6.592	10.465	8.875		
ITS (Dry), kPa	L = (2*K*1,000,000)/(3.142*Ht*Dia)	959	831	917	862					892	
ITS (Wet) kPa	M = (2*K*1,000,000)/(3.142*Ht*Dia)					769	649	1047	888	838	
Tensile Strenght Ratio (TSR)	N = 100*M/L									94.0	≥80%
ITS Loss (%)	N-100%									6.0	≤20%

Tested by: Mbele Margerate Checked by: Eng. N.O. Parapara
Date: 18/02/2025 Date: 18/02/2025

Source: Field survey, 2025

3

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -AASHTO T283

CLIENT'S NAME: Engr. N.O. Parapara.
PROJECT NAME: Thesis project for master of scienceth civil Engineering
JOB DESCRIPTION: SUPERPAVE specimen moulded at 208 gyrations (polymer modified using 4.2% SBS)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade Bitumen
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE Aggregates from Katani quarry in Mlolongo & Bitumen from Local supplier
DATE TESTED: 11/02/2025
LABORATORY: Bitumen

ITS TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET				CONDITIONED SET				AVERAGE	REMARKS
		1ST SET				2ND SET					
Sample ID		S5	S6	S7	S8	S1	S2	S3	S4		
Diameter, mm	Dia	100	100	100	100	100	100	100	100		
Sample Height, mm	Ht	66.039	65.840	65.850	65.464	64.586	66.216	65.341	65.961		
Wt. in air, g	A	1061	1058	1057	1060	1038	1070	1053	1060		
Wt. in water, g	B	592	592	594	594	582	600	590	594		
SSD Wt., g	C	1064	1062	1064	1066	1043	1075	1059	1066		
Volume, cm3	D=C - B	472	470	470	472	461	475	469	472		
Water Absorption	E=100*[(C-A)/D]	0.64	0.85	1.49	1.27	1.08	1.05	1.28	1.27		
Bulk Spec. Gravity, Gmb	F= A/D	2.248	2.251	2.249	2.246	2.252	2.253	2.245	2.246		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	5.591	5.457	5.547	5.680	5.434	5.391	5.703	5.680	5.569	6' - 8
Maximum Load, kN	K	8.568	8.988	8.845	10.402	8.729	9.038	9.536	8.354		
ITS (Dry), kPa	L = (2*K*1,000,000)/(3.142*Ht*Dia)	826	870	856	1012					891	
ITS (Wet) kPa	M = (2*K*1,000,000)/(3.142*Ht*Dia)					861	869	930	807	867	
Tensile Strenght Ratio (TSR) %	N = 100*M/L									97.3	≥80%
ITS Loss (%)	N-100%									2.7	≤20%

Tested by: Margarate Mbele
Date: 11/02/2025
Checked by: Engr. N.O Parapara
Date: 11/02/2025

Source: Field survey, 2025

4

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -AASHTO T283

CLIENT'S NAME: Eng. N.O. Parapara
PROJECT NAME: Thesis project for Master of Science in Civil Engineering
JOB DESCRIPTION: Marshall specimen moulded at 75 blows (Polymer modified using 4.2% SBS)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade Bitumen
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE Aggregates sourced from Katani Quarry in Mlolongo & Bitumen from Local supplier
DATE TESTED: 18/02/2024
LABORATORY:

ITS TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET				CONDITIONED SET				AVERAGE	REMARKS
		1ST SET				2ND SET					
Sample ID		M9	M10	M11	M12	M13	M14	M15	M16		
Diameter, mm	Dia	101	101	101	101	101	101	101	101		
Sample Height, mm	Ht	65	64	64	63	65	63	65	63		
Wt. in air, g	A	1154	1147	1138	1140	1178	1151	1141	1135		
Wt. in water, g	B	646	641	638	640	660	644	641	639		
SSD Wt., g	C	1159	1151	1139	1145	1180	1153	1147	1138		
Volume, cm3	D=C - B	513	510	501	505	520	509	506	499		
Water Absorption	E=100*[(C-A)/D]	0.97	0.78	0.20	0.99	0.38	0.39	1.19	0.60		
Bulk Spec. Gravity, Gmb	F= A/D	2.250	2.249	2.271	2.257	2.265	2.261	2.255	2.275		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381	
% air voids	H = 100*[1-(F/G)]	5.522	5.543	4.601	5.190	4.856	5.027	5.294	4.471	5.063	6' - 8
Maximum Load, kN	K	8.020	7.623	8.658	8.114	7.417	6.820	6.092	9.115		
ITS (Dry), kPa	L = (2*K*1,000,000)/(3.142*Ht*Dia)	778	751	853	812					798	
ITS (Wet) kPa	M = (2*K*1,000,000)/(3.142*Ht*Dia)					719	682	591	912	726	
Tensile Strenght Ratio (TSR)	N = 100*M/L									91.0	≥80%
ITS Loss (%)	N-100%									9.0	≤20%

Tested by: Margarate Mbele
Date: 18/02/2025
Checked by: Eng. N.O. Parapara
Date: 18/02/2025

Source: Field survey, 2025

APPENDIX I

Marshall Stability and Loss of Marshall Stability (ASTM D1559) Test Results

5 5

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -ASTM D1559

CLIENT`S NAME: Eng. N.O. Parapara
PROJECT NAME: Thesis project for Master of Science in Civil Engineering
JOB DESCRIPTION: SUPERPAVE specimen moulded at 205 gyrations (Neat)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade Bitumen
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE: Aggregates sourced from Katani Quarry in Mlolongo & Bitumen from a local supplier
DATE TESTED: 11/02/2025
LABORATORY: Bitumen

MARSHALL STABILITY (IMMERSION) TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET				CONDITIONED SET				AVERAGE	REMARKS
		1ST SET				2ND SET					
Sample ID		N13	N14	N15	N16	N9	N10	N11	N12		
Diameter, mm	Dia	100	100	100	100	100	100	100	100		
Sample Height, mm	Ht	65.942	65.875	65.816	65.954	65.425	65.475	65.382	66.416		
Wt. in air, g	A	1058	1058	1058	1056	1052	1053	1052	1059		
Wt. in water, g	B	592	592	592	592	592	592	592	592		
SSD Wt., g	C	1065	1065	1064	1063	1059	1058	1058	1068		
Volume, cm3	D=C - B	473	473	472	471	467	467	466	476		
Water Absorption	E=100*[(C-A)/D]	1.48	1.48	1.27	1.49	1.50	1.07	1.29	1.89		
Bulk Spec. Gravity, Gmb	F= A/D	2.237	2.237	2.242	2.242	2.253	2.260	2.258	2.225		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	6.057	6.057	5.858	5.836	5.389	5.096	5.186	6.561	5.755	3' - 7
Maximum Load, kN	K	14.093	14.656	18.091	15.812	12.557	13.442	12.998	13.696		
Volume Correction Factor	L	1.14	1.14	1.14	1.14	1.190	1.19	1.19	1.14		
Corrected Stability	M = K*L	16066	16708	20624	18026	14943	15996	15468	15613	16680	
Average Stability, N	N		17856					15505			
Retained Marshall Stability (%)	P=100*(2nd set/1st Set)				86.8						≥75%
Stability Loss (%)	P-100%				13.2						≤25%

Tested by: Margerate Mbele — Checked by: Eng. N.O. Parapara
Date: 11/02/2025 — Date: 11/02/2025

Source: Field survey, 2025

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MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -ASTM D1559

CLIENT`S NAME: Eng. N.O. Parapara
PROJECT NAME: Thesis project for Master of science in Civil Engineering
JOB DESCRIPTION: Marshall specimen moulded at 75 blows (Neat)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade bitumen
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE: Aggregates sourced from Katani Quarry in Mlolongo & Bitumen from Local supplier
DATE TESTED: 11/02/2025
LABORATORY: Bitumen

MARSHALL STABILITY (IMMERSION) TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET				CONDITIONED SET				AVERAGE	REMARKS
		1ST SET				2ND SET					
Sample ID		N1	N2	N3	N4	N5	N6	N7	N8		
Diameter, mm	Dia	101	101	101	101	101	101	101	101		
Sample Height, mm	Ht	64	63	63	63	64	63	64	64		
Wt. in air, g	A	1136	1132	1135	1125	1146	1132	1135	1143		
Wt. in water, g	B	637	637	636	630	641	637	635	643		
SSD Wt., g	C	1139	1134	1138	1128	1149	1134	1138	1148		
Volume, cm3	D=C - B	502	497	502	498	508	497	503	505		
Water Absorption	E=100*[(C-A)/D]	0.60	0.40	0.60	0.60	0.59	0.40	0.60	0.99		
Bulk Spec. Gravity, Gmb	F= A/D	2.263	2.278	2.261	2.259	2.256	2.278	2.256	2.263		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	4.958	4.340	5.042	5.122	5.254	4.340	5.231	4.941		3' - 7
Maximum Load, kN	K	16.640	11.440	13.564	14.710	13.147	16.410	13.845	13.386		
Volume Correction Factor	L	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04		
Corrected Stability	M = K*L	17306	11866	14107	15298	13678	17066	14399	13921		
Average Stability, N	N		14644				14765				
Retained Marshall Stability (%)	P=100*(2nd set/1st Set)				100.8						≥75%
Stability Loss (%)	P-100%				-0.8						≤25%

Tested by: Margerate Mbele — Checked by: Eng. N.O. Parapara
Date: 11/02/2025 — Date: 11/02/2025

Source: Field survey, 2025

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -ASTM D1559

CLIENT`S NAME: Eng. N.O. Parapara
PROJECT NAME: Thesis project for Master of science in Civil Engineering
JOB DESCRIPTION: Superpave specimen moulded at 205 gyrations (polymer modified using 4.2% SBS)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade Bitumen
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE Aggregates sourced from Kataani quarry in Mlolongo & Bitumen from local supplier
DATE TESTED: 11/02/2025 LABORATORY: Bitumen

MARSHALL STABILITY (IMMERSION) TEST RESULTS

TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET				CONDITIONED SET				AVERAGE	REMARKS
		1ST SET				2ND SET					
Sample ID		S13	S14	S15	S16	S9	S10	S11	S12		
Diameter, mm	Dia	100	100	100	100	100	100	100	100		
Sample Height, mm	Ht	66.329	66.676	66.466	66.006	65.925	65.647	64.183	67.423		
Wt. in air, g	A	1055	1057	1054	1054	1053	1055	1058	1055		
Wt. in water, g	B	588	591	591	594	590	592	594	591		
SSD Wt., g	C	1061	1064	1061	1061	1059	1061	1064	1060		
Volume, cm3	D=C - B	473	473	470	467	469	469	470	469		
Water Absorption	E=100*[(C-A)/D]	1.27	1.48	1.49	1.50	1.28	1.28	1.28	1.07		
Bulk Spec. Gravity, Gmb	F= A/D	2.230	2.235	2.243	2.257	2.245	2.249	2.251	2.249		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	6.323	6.146	5.815	5.210	5.703	5.524	5.457	5.524	5.713	3' - 7
Maximum Load, kN	K	16.179	18.304	16.202	17.057	16.477	14.260	13.720	14.317		
Volume Correction Factor	L	1.14	1.14	1.19	1.19	1.19	1.19	1.19	1.19		
Corrected Stability	M = K*L	18444	20867	19280	20298	19608	16969	16327	17037	18604	
Average Stability, N	N			19722				17485			
Retained Marshall Stability (%)	P=100*(2nd set/1st Set)				88.7						≥75%
Stability Loss (%)	P-100%				11.3						≤25%

Tested by: Margerate Mbele Checked by: Eng. N.O. Parapara
Date: 11/02/2025 Date: 11/02/2025

Source: Field survey, 2025

MINISTRY OF ROADS AND TRANSPORT
MATERIALS TESTING & RESEARCH DIRECTORATE
MOISTURE SUSCEPTIBILITY TEST -ASTM D1559

CLIENT`S NAME: Eng. N.O. Parapara
PROJECT NAME: Thesis project for Master of science in Civil Engineering
JOB DESCRIPTION: Marshall specimen moulded at 75 blows (polymer modified using 4.2% SBS)
SAMPLE DESCRIPTION: Aggregates & 60/70 penetration grade Bitumen
DATE RECEIVED: 09/12/2024
MATERIAL SOURCE Aggregates sourced from Kataani quarry in Mlolongo & Bitumen from a local su
DATE TESTED: 11/02/2025 LABORATORY: Bitumen

MARSHALL STABILITY (IMMERSION) TEST RESULTS

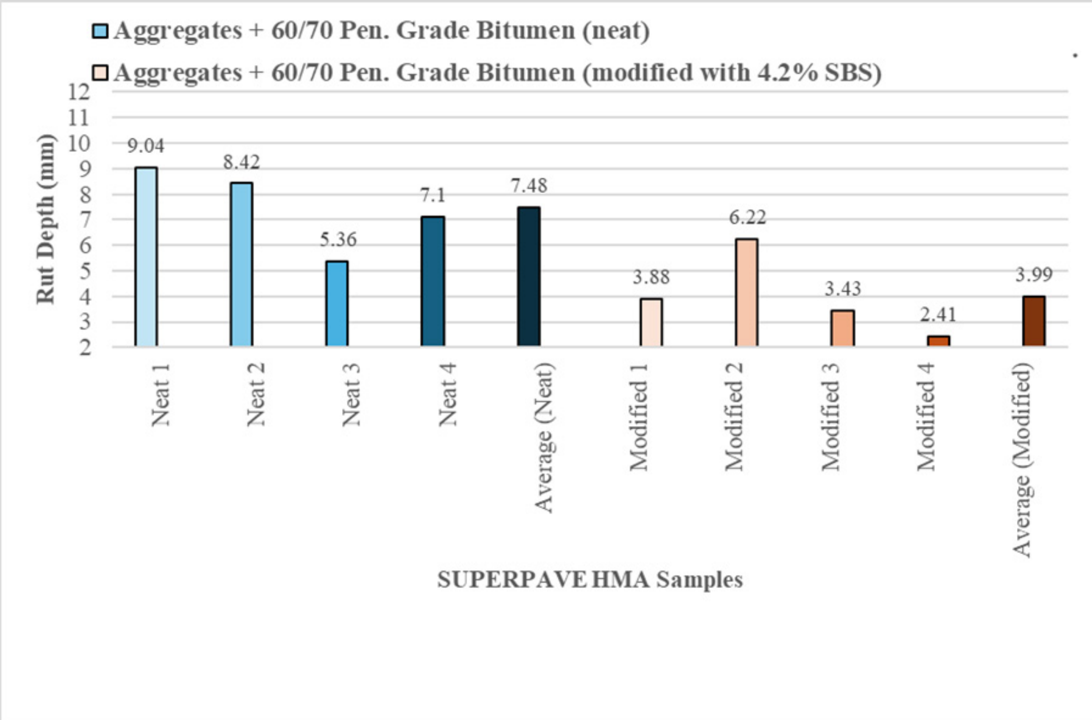
TEST DESCRIPTION	FORMULAR	UNCONDITIONED SET				CONDITIONED SET				AVERAGE	REMARKS
		1ST SET				2ND SET					
Sample ID		M1	M2	M3	M4	M5	M6	M7	M8		
Diameter, mm	Dia	101	101	101	101	101	101	101	101		
Sample Height, mm	Ht	64	64	65	64	64	63	64	64		
Wt. in air, g	A	1143	1160	1157	1154	1162	1118	1152	1156		
Wt. in water, g	B	644	652	644	648	652	631	643	648		
SSD Wt., g	C	1145	1163	1156	1155	1169	1120	1157	1160		
Volume, cm3	D=C - B	501	511	512	507	517	489	514	512		
Water Absorption	E=100*[(C-A)/D]	0.40	0.59	0.98	0.20	1.35	0.41	0.97	0.78		
Bulk Spec. Gravity, Gmb	F= A/D	2.281	2.270	2.248	2.276	2.248	2.286	2.241	2.258		
Max. Spec. Gravity, Gmm	G	2.381	2.381	2.381	2.381	2.381	2.381	2.381	2.381		
% air voids	H = 100*[1-(F/G)]	4.182	4.659	5.584	4.404	5.603	3.977	5.870	5.174	5.102	3' - 7
Maximum Load, kN	K	14.237	13.589	15.512	17.728	11.015	14.917	10.451	16.262		
Volume Correction Factor	L	1.04	1.00	1.00	1.04	1.00	1.09	1.00	1.00		
Corrected Stability	M = K*L	14806	13.589	15.512	18.437	11.015	16260	10451	16262	14542	
Average Stability, N	N			15586				13497			
Retained Marshall Stability (%)	P=100*(2nd set/1st Set)				86.6						≥75%
Stability Loss (%)	P-100%				13.4						≤25%

Tested by: Margerate Mbele Checked by: Eng. N.O. Parapara
Date: 11/02/2025 Date: 11/02/2025

Source: Field survey, 2025

APPENDIX J

Rut depth graph results for the SUPERPAVE HMA sample for neat and polymer-modified



Source: Field survey, 2025