Marshall Asphalt Mix and Superior Performance Asphalt Mix in Oman: A Comparative Study

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ABSTRACT

The mix design procedure used in Superior Performance Asphalt Pavements (Super-pave) was created by the Strategic Highway Research Program (SHRP) in response to the limitations and empirical approach of Marshall methodology. This study aims to compare the Marshall asphalt mixture design method with the Super-pave asphalt mixture design procedures. Locally available aggregates commonly used in asphalt concrete mixtures in Oman were used. The asphalt mixtures were made with aggregate and asphalt-binder with a penetration grade of 60/70 and PG 64-10. Samples from two mixes were made accordingly. Volumetric properties analysis, flow, Marshall stability, and loss of Marshall stability tests were carried out. According to the study findings, the optimum asphalt composition was 4.5% when utilizing the Marshall methodology and 5.5% when using the Super-pave approach. Furthermore, the Super-pave specimens showed less loss of Marshall stability (22.22%) than the Marshall specimen (30.09%).

Keywords-asphalt mix; Super-pave method; Marshall method; volumetric properties; asphalt performance

I. INTRODUCTION

The design of asphalt mixes for tropical climates with high temperatures, especially for roads that are projected to handle huge truck loads and higher design traffic volumes much greater than 1 million Equivalent Single Axle Loads (ESALs) is a challenging task. The primary concern when designing such an asphalt mix is making sure the mix is resistant to plastic deformation [1]. The current level of practice for pavement design is mostly based on empirical approaches in various nations of the Gulf Cooperative Council (GCC). Although, various institutions have relied on the Superior AASHTO 1993 pavement design guide [2].

In Oman, the Marshall mix design technique is mostly utilized to create asphalt concrete mixes that meet the international requirements. However, due to the harsh environmental conditions and heavy traffic loads, several of these roads exhibit serious distress after only a short time in use [3], leading to increased maintenance costs. According to [4], tropical climatic conditions are the primary factor that affects the materials used on roads. In order to improve the physical properties of Marshall asphalt mixtures at moderate to high temperatures, authors in [5] examined the impacts of utilizing improved bitumen binders as well as additives taking into account flexible asphalt mixtures of AC 40/60 only. However, the continued usage of the Marshall process for asphalt mixtures is another factor that is contributing to early distresses. Since the Marshall mix technique is empirical, it has a limited ability to accurately predict how changes in environmental and loading variables, as well as material qualities and kinds, will affect the performance of the pavement. It is unable to recognize mixtures that are prone to shear. The Marshall mix method's impact compaction method does not accurately represent the densification that occurs in an actual pavement during traffic as presented in [6]. Due to such constraints, SHRP created the Super-pave design procedure to address the challenges of the Marshall process. SHRP focused on creating performance-based standards for asphalt binders and mixes [6, 7], with the aim of developing design mixtures that consist of a performance-based asphalt binder requirement and enhanced performance-based tests.

Although researchers have used the Super-pave technology in different geographical locations [8-10], given the climatic and environmental conditions, the effectiveness of Super-pave design has not been fully ascertained in the Oman region. The most frequent bitumen grade utilized in asphalt mixtures in this region is the asphalt binder 60/70 penetration grade for Marshall mixtures [11]. However, the Super-pave Performance Grading (PG) system appropriately takes into account the pavement conditions as it links the measured physical qualities of asphalt binders with field performance [12, 13]. Although other elements, such as the geographic location, also play a significant influence, air temperature has the greatest impact on pavement temperature. The Super-pave PG grading system has two temperature limits. For instance, asphalt with a PG 64-10 can perform satisfactorily in the temperature range of 64 °C-10 °C [14]. Authors in [15] created models for four high-temperature grades: PG 52, 58, 64, and 70, while low temperatures were limited to PG-10 and PG-16. However, the recommendation from [11] included asphalt binder of PG 64-10 for Oman with 95% dependability. The environmental factors affect the engineering properties [9, 13, 14, 16, 17].

This paper reports the results of an experimental investigation regarding the performance of asphalt mixtures using asphalt binder with 60/70 penetration grade and PG 64-10. The Marshall process for secondary compaction and plastic deformation capability was compared with the Super-pave mix design process. Various factors influencing the mix design procedures were studied.

II. MARSHALL MIX DESIGN VS SUPERIOR PERFORMING ASHALT PAVEMENT

Asphalt mix is a composite material that is extensively used in road building. It is also known as asphalt concrete or merely asphalt. A composite is composed of elements that can enhance the physical and chemical properties of the separate elements [18]. Asphalt is made up of aggregates (crushed stone, gravel, and sand) and asphalt binder (bitumen). The aggregates give the mixture strength and stability, while the asphalt binder keeps the aggregates together and provides flexibility.

In tropical regions, Marshall mix design is the most widely employed method [3, 10]. However, this approach has several limitations, including the fact that it is an ineffective method for identifying mixes that are susceptible to plastic deformations and voids following extensive compaction that does not match field compaction [19]. The conventional Marshall metric, does not account for the in air-voids that asphalt mixes encounter during the second and third compactions phases. The initial Marshall mix design process should be extended by incorporating a further compaction effort to replicate the consolidated condition of asphalt near the end of its usable life [20]. Authors in [21] studied how variations from the Job Mix Formula (JMF) within the aggregate gradients of Marshall asphalt mixes affected the overall performance of the combinations. On the other hand, the SHRP led to the development of superior performing asphalt pavements. The initiative lasted from 1987 to 1993, followed by a period of execution. The objective of the initiative was the improvement of the highway system's efficacy, longevity and reliability. It tends to generate new approaches that consider load of traffic and environmental issues. Consequently, techniques for evaluating asphalt binders and analyzing mixtures were developed [22]. A novel method of specifying, testing, and designing asphalt materials is the Super-pave. It is an improved approach for identifying asphalt pavement constituents, developing and analyzing asphalt mixtures, and forecasting asphalt pavement performance. Super-pave has shown the potential of being very suitable for tropical climate regions and has been recommended for use in both developing and developed nations [23].

The size and weight of the tested sample are the first significant ways that the Marshall asphalt mix differs from the Super-pave mix. Marshall mix has a diameter of around 102 mm, a height of approximately 64 mm, and a weight of approximately 1200 g. Super-pave, on the other hand, weighs about 4700g and has a diameter of 150 mm with a height of roughly 115 mm. In order to determine the ideal binder content, Super-pave mix's binder content is acquired using the maximum nominal sieve [22]. In contrast, the amount of asphalt in Marshall mix is determined through a trial-and-error process. Thirdly, the manner of compacting in the Marshall method and the super-pave method is different. In the Marshall method, the mix is compacted using a Marshall mix hammer while gyratory machine is used in Super-pave. Also, the Super-pave mix considers heavy traffic loads, unlike the Marshall mix. Figures 1 and 2 show the Marshal test preparation and Marshall compaction. Furthermore, the Marshall approach employs a subpar technique to discover mixes prone to permanent deformation [3, 9]. It is reported that the Super-pave-designed mixtures have a lesser possibility for rutting and a lower life cycle cost [24]. This study investigates how well the Super-pave design approach, with the use of local materials, performs when compared to Marshal design under conditions of strong traffic loading and prevalent temperatures.

Fig. 1. Marshall test preparation.

Fig. 2. Marshall compaction.

III. STABILITY IN PAVEMENT DESIGN

Stability in an asphalt concrete pavement is the ability to withstand deformation when been subject to traffic loads under different environmental conditions. As a condition, when subjected to repeated loads, a stable pavement keeps its shape and smoothness. According to [19], as stability rises, density also rises whereas air spaces decline. By increasing the number of gyrations, the gyratory compactor's effort is increased as volume of traffic rise. This increase in the gyratory efforts leads to increase in stability.

Thus, it is essential to understand stability and its role in the overall performance of asphalt concrete pavement. Stability analysis and specifications are detailed in the relevant codes of practice. This phenomenon is discussed in the subsequent sections.

IV. METHODOLOGY

The Marshall mix design specifications detailed in ASTM [20] and that of Super-pave mix design based on AASHTO guidelines were followed, based on the utilization of regional Oman aggregates and binders for asphalt. In the next subsections, the techniques are described.

A. Material Selection

Materials that complied with the requirements and were frequently used in road construction in Oman were chosen from local sources. Crushed limestone was employed the coarse aggregates, while natural, rounded silica sand in accordance with [25] was used as fine aggregates. Using lime-filler and aggregates of sizes 19 mm were acquired within the Province of Oman as well as bituminous grade of 60/70, a thorough laboratory investigation was conducted and the overall aggregate gradation is given in Fiure 3. The aggregates and the asphalt binder utilized to create the asphalt mixtures that had penetration performance grade of PG 64-10. To achieve the study objectives, the asphalt mixtures were prepared using both Super-pave and Marshall design approaches.

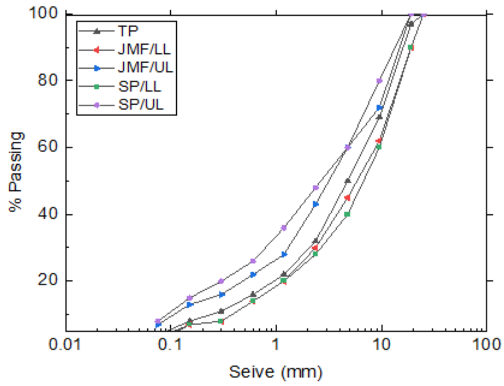

Fig. 3. Overall aggregate gradation. TP: Total Passing, JMF: Job Mix Formula, SP: Specification, UL: Upper Limit, and LL: Lower Limit.

TABLE I. MARSHALL JOB MIX

Sieve (mm)	Job Mix Formula		Fraction mass (g)	Cumulative fraction mass (g)	Bitumen mass (g)				
	Total passing (%)	Retained (%)			3.0%	3.5%	4.0%	4.5%	5.0%
25.0	100	0	0	0	37.1	43.5	50.0	56.5	63.2
19.0	97	3	36	36					
9.50	69	28	336	372					
4.75	50	19	228	600					
2.36	32	18	216	816					
1.18	22	10	120	936					
0.60	16	6	72	1008					
0.30	11	5	60	1068					
0.15	8	3	36	1104					
0.075	4	4	48	1152					
(-) 0.075			48	1200					
Total batch mass (g)					1237.1	1243.5	1250.0	1256.5	1263.2

1) Marshall Mix Design

The Marshall mix design procedure was carried out in accordance with ASTM specifications. In a 100 mm diameter cylindrical mold, the samples were subjected to 75 blows on each side. Five samples with bitumen content were prepared in accordance with Oman design, namely 3%, 3.5%, 4%, 4.5%, and 5%. Following that, Marshall stability and flow tests were performed to determine the optimum bitumen content that proved to be an asphalt mix with 4% air-voids. In this investigation, the optimal asphalt concentration was 4.50% of the overall mass of the mix. At the obtained optimal content, the values of Marshall-stability, flows, and voids in asphalt and in aggregate minerals were determined. Aggregate preparation was done according to the job mix. The aggregate weight used for Marshall pavement and for the Super-pave was 1200 g and 4700 g, respectively. Table I shows Marshall JBF.

2) Super-pave Mix Design Method

The mix was prepared in accordance with [22]. Super-pave uses volumetric analysis for the mix design in the testing and analysis processes. The optimal asphalt content for the selected structure is chosen after selecting a design aggregate structure. The nominal maximum size of aggregates gave the initial bitumen content. The three more bitumen content values where achieved in the order of +0.5, -0.5, and +1. In this study, the nominal maximum size of aggregates was 19 mm, and the bitumen percentage was 4%, 4.5%, 5% and 5.5%. The Super-pave job mix is shown in Table II.

Both mean design high temperatures of the region and the design ESALs affected how many gyrations were applied. For Oman, a traffic frequency between ten and thirty millions ESALs was selected to simulate moderate traffic, which corresponds to the traffic situation of the majority of the region's road network, with summertime temperatures reaching 50 °C [26]. The maximum required number of gyrations, N is 220. So, all sample preparations of the Super-pave mix trials utilized in the research used 160 gyrations.

The mixture was properly prepared, a filter paper was placed in the super-pave mold, the asphalt was applied in three layers, and the surface was flattened. The super-pave mold was loaded into the Gyratory compacting machine. Figures 4 and 5 show the Super-pave mold preparation and the gyration compaction, respectively. Systematic calculations for the Super-pave design based on design criteria were adopted [22].

TABLE II. SUPER-PAVE JOB MIX

Sieve (mm)	Job Mix Formula		Fraction mass (g)	Cumulative fraction mass (g)	Bitumen mass (g)			
	Total passing (%)	Retained (%)			4.0%	4.5%	5.0%	5.5%
25	100	0	0	0	195.8	221.5	247.4	273.5
19	97	3	141	141				
9.5	69	28	1316	1457				
4.75	50	19	893	2350				
2.36	32	18	846	3196				
1.18	22	10	470	3666				
0.6	16	6	282	3948				
0.3	11	5	235	4183				
0.15	8	3	141	4324				
0.075	4	4	188	4512				
(-) 0.075			188	4700				
Total batch mass (g)					4895.8	4921.5	4947.4	4973.5

Fig. 4. Super-pave mold preparation.

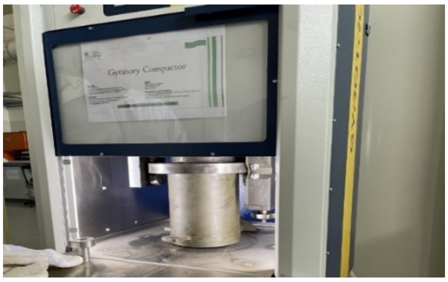

Fig. 5. Gyratory compaction.

V. RESULTS AND DISCUSSION

A. Performance Evaluation

A comparison of the results of the Marshall and Super-pave mix design techniques was performed in other to evaluate their effectiveness. The specimens were prepared following the optimum mix design asphalt contents as obtained, AC 4.5% (Marshall) and AC 5.5% (Super-pave), utilizing the gradation properties of the local recommendations (see Figure 3). The test specimens were compacted utilizing a gyratory compactor for the Super-pave mixes and a Marshall's 75-blow compactor for the Marshall mixes in order to reach the 4% air void target. Marshall stability, loss of Marshall stability, and volumetric properties were studied.

1) Marshall Stabilities / Loss of Marshall stabilitiy

Following the ASTM D 6927 [27] procedure, 6 specimens from each individual mix were prepared and placed in a 60 ^{0}C water bath for 30 min before 3 of them were tested for Marshall stability. After 24 hr, the remaining 3 specimens were also examined. Figure 6 demonstrates the outcomes for the tested specimens. The result shows that Super-pave bath specimens have higher Marshall stability than the Marshall specimens, for both initial and wet stability values. Furthermore, the Super-pave specimens showed less loss of Marshall stability (22.22%) than the Marshall specimens (30.09%), which is in agreement with the findings in [9]. The Super-pave specimens outperformed the Marshall specimens due to their improved aggregate structure and their lower dust proportion.

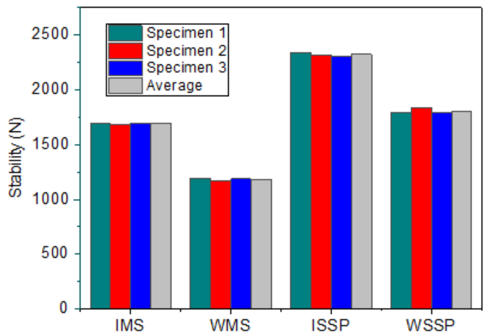

Fig. 6. Stability test results. IMS: Initial Marshall Stability, WMS: Wet Marshall Stability, ISSP: Initial Stability Super-pave, WSSP: Wet Stability Super-pave.

2) Volumetric Property Analysis

Figures 7-9 show the results of the volumetric properties of the tested specimens. They demonstrate the variations in the Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), and Voids in Total Mix (VTM) at 4% air void for the optimum asphalt content of both mixes. It is observed from Figure 7 that VFA% for Marshall is 70% and 71% for Super-pave which is within the 65–78% criterion [6]. In Figure 8, it is observed that VMA% for Marshall and Super-pave is 13.2% and 14.0%, respectively. Again, these values are satisfactory. Figure 9 shows that the VTM% for both Marshall and Super-pave is 4%. This finding is consistent with the observation in [28] that aggregate gradation has a significant impact on pavement characteristics. From these findings, it can be concluded that Super-pave has higher volumetric properties than Marshall in hot environment and high-traffic conditions.

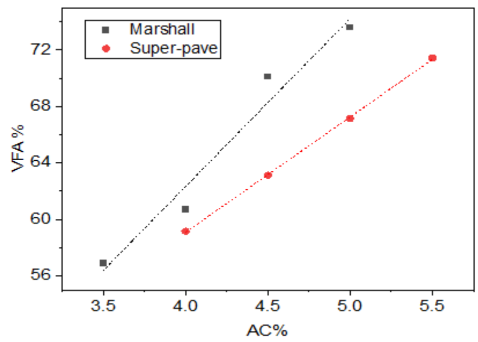

Fig. 7. VFA% for Marshall and Super-pave mixes.

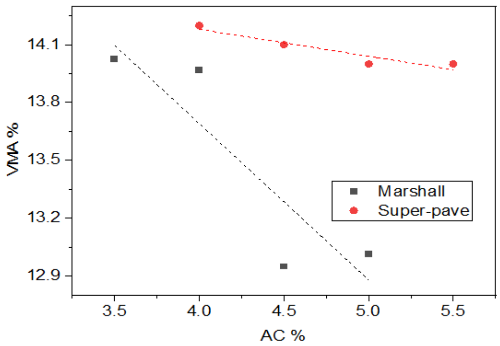

Fig. 8. VMA% for Marshall and Super-pave mixes.

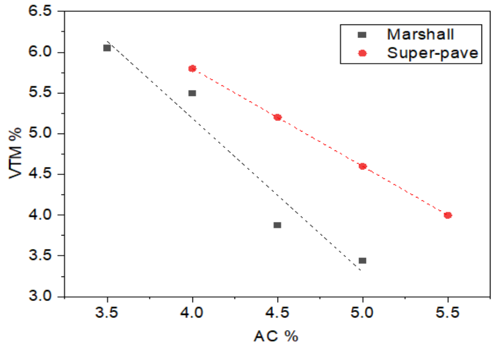

Fig. 9. VTM% for Marshall and Super-pave mixes.

1) Density, Flow, and Dust Proportion

In Table III, the values of the selected Marshall properties are shown. At optimum asphalt content of 4.5%, the bulk density G_{mm} is 2.41 g/cm^3 and the Flow is 4 mm. Table IV shows the selected Super-pave properties.

At optimum asphalt content of 5.5%, Dp_{est} is 0.77 which is within the required range of 0.6 – 1.2. Bulk density at optimum asphalt content = $G_{mm} \times 96\% = 2.530 \times 96\% = 2.428$. Therefore, the findings show that Super-pave design has higher density (2.4282 g/cm^3) than the Marshall mix design. This superior performance shows that the use of Super-pave mix design for pavements in Oman can endure stresses due to harsh weather and heavy traffic more efficiently.

TABLE III. MARSHALL SELECTED PROPERTIES

AC%	AC	G_{mm}	G_{mb}	Flow	G_{sb}
3	0.03	2.53	2.342	2.1	2.668
3.5	0.035	2.53	2.377	2.7	2.668
4	0.04	2.53	2.391	3.2	2.668
4.5	0.045	2.53	2.412	4	2.668
5	0.05	2.53	2.433	4.9	2.668

AC: Asphalt Content, G_{sb}: aggregate specific gravity, G_{mb}: average bulk specific gravity

TABLE IV. SUPER-PAVE SELECTED PROPERTIES

AC%	%G_{mm} at ND	%G_{mm} at N_{in}	DP_{est}
4	94.2	84.6	0.90
4.5	94.8	84.5	0.85
5	95.4	84.7	0.81
5.5	96.0	86.6	0.77

%G_{mm} at N_{in}: %maximum theoretical density, N_i: initial number of gyrations, DP_{est}: estimated dust proportion.

VI. CONCLUSION

The performance of the Super-pave and the traditional Marshall approaches under high-traffic loading, considering locally sourced materials and typical weather conditions, were investigated in this study. The reached conclusions include the following:

- The optimum percentages by weight of asphalt constituent of the Super-pave and Marshall mixes were determined as 5.5% and 4.5%. As a result, Super-pave mix design yields higher binder content than Marshall in hot environment and high-traffic conditions.
- Volumetric properties, VMA, VFA, and VTM for Super-pave mixes were found to be 14%, 71%, and 4% respectively and 13%, 70 %, and 4% for the Marshall mixes. Again, Super-pave mixes reveal higher volumetric properties than Marshall mixes.
- The Super-pave specimens showed less loss of Marshall stability (22.22%) than the Marshall specimens (30.09%). This could be caused by the improved aggregate structure and the lower dust proportion of the Super-pave mixes.
- Super-pave and Marshall specimen densities were found to be 2.43 g/cm^3 and 2.41 g/cm^3 at optimal asphalt content. The relatively higher Super-pave density could be due to the involvement of the Super-pave gyration compactor.
- The Super-pave mixes outperformed the Marshall mixes. As a result, prioritizing the Super-pave design approach in Oman may resolve some of the problems associated with the recently built roads.

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REFERENCES

[1] H. M. A. A. Kareem and A. H. K. Albayati, "The Possibility of Minimizing Rutting Distress in Asphalt Concrete Wearing Course," *Engineering, Technology & Applied Science Research*, vol. 12, no. 1, pp. 8063–8074, Feb. 2022, https://doi.org/10.48084/etasr.4669.

[2] D. M. Mrawira and F. Elizondo, "Mechanistic Characterization of Superpave Asphalt Mixes in Costa Rica," *Road Materials and Pavement Design*, vol. 9, no. sup1, pp. 115–134, Jan. 2008, https://doi.org/10.1080/14680629.2008.9690162.

[3] I. M. Asi, "Performance evaluation of SUPERPAVE and Marshall asphalt mix designs to suite Jordan climatic and traffic conditions," *Construction and Building Materials*, vol. 21, no. 8, pp. 1732–1740, Aug. 2007, https://doi.org/10.1016/j.conbuildmat.2006.05.036.

[4] J. Ahmad, N. I. M. Yusoff, M. R. Hainin, M. Y. A. Rahman, and M. Hossain, "Evaluation on Performance Characteristics of Superpave Asphalt Mix Design under Tropical Climatic Conditions," *International Journal of Pavement Research and Technology*, vol. 7, no. 5, pp. 331–342, Sep. 2014, https://doi.org/10.6135/ijprt.org.tw/2014.7(5).331.

[5] S. H. Arif, N. M. Abdulah, T. A. Mohsin, and V. A. Musa, "Additives Influence on the Properties of Asphalt Binders: A Case Study," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10565–10570, Apr. 2023, https://doi.org/10.48084/etasr.5789.

[6] F. L. Roberts, L. N. Mohammad, and L. B. Wang, "History of Hot Mix Asphalt Mixture Design in the United States," *Journal of Materials in Civil Engineering*, vol. 14, no. 4, pp. 279–293, Aug. 2002, https://doi.org/10.1061/(ASCE)0899-1561(2002)14:4(279).

[7] E. R. Brown, P. S. Kandhal, and J. Zhang, *Performance Testing For Hot Mix Asphalt*. Auburn, AL, USA: Auburn University, 2001.

[8] D. E. Watson, E. R. Brown, and J. Moore, "Comparison of Superpave and Marshall Mix Performance in Alabama," *Transportation Research Record*, vol. 1929, no. 1, pp. 133–140, Jan. 2005, https://doi.org/10.1177/0361198105192900116.

[9] P. Jitsangiam, P. Chindaprasirt, and H. Nikraz, "An evaluation of the suitability of SUPERPAVE and Marshall asphalt mix designs as they relate to Thailand's climatic conditions," *Construction and Building Materials*, vol. 40, pp. 961–970, Mar. 2013, https://doi.org/10.1016/j.conbuildmat.2012.11.011.

[10] S. M. Omar, B. M. Sharif, H. U. Ahmed, and W. A. Abdullah, "Comparison Study between Marshall and Superpave Mix Design Methods," *Halabja University Journal*, vol. 6, no. 1, pp. 348–365, Mar. 2021, https://doi.org/10.32410/huj-10376.

[11] M. Abo-Hashema, R. M. Mousa, S. Al-Zedjali, Q. Balushi, M. Metwally, and M. Al-Rashdi, "Development of Oman Performance Grade Paving Map for Superpave Asphalt Mix Design," in *19th Annual International Conference on Highway, Airports Pavement Engineering, Infrastructures & Asphalt Technology*, Liverpool, UK, Mar. 2020, pp. 1–21.

[12] W. Zeiada *et al.*, "Review of the Superpave performance grading system and recent developments in the performance-based test methods for asphalt binder characterization," *Construction and Building Materials*, vol. 319, Feb. 2022, Art. no. 126063, https://doi.org/10.1016/j.conbuildmat.2021.126063.

[13] A. Lekea and W. J. vdM Steyn, "Performance of Pavement Temperature Prediction Models," *Applied Sciences*, vol. 13, no. 7, Jan. 2023, Art. no. 4164, https://doi.org/10.3390/app13074164.

[14] S. Khedr and M. Saudy, "Development of superpave regional implementation framework in developing countries with hot and arid climates: Egyptian case study," *Case Studies in Construction Materials*, vol. 18, Jul. 2023, Art. no. e01772, https://doi.org/10.1016/j.cscm.2022.e01772.

[15] H. F. Hassan, A. Al-Nuaimi, S. Al-Oraimi, and T. M. A. Jafar, "Development of asphalt binder performance grades for Omani climate," *Construction and Building Materials*, vol. 22, no. 8, pp. 1684–1690, Aug. 2008, https://doi.org/10.1016/j.conbuildmat.2007.06.016.

[16] V. T. Ibeabuchi, C. U. Nwoji, and B. C. Eneh, "Effects of Cooling Methods on the Properties of Concrete with Metakaolin after Thermal Exposure," *IOP Conference Series: Earth and Environmental Science*, vol. 1054, no. 1, Jun. 2022, Art. no. 012042, https://doi.org/10.1088/1755-1315/1054/1/012042.

[17] V. T. Ibeabuchi, C. U. Nwoji, and C. Esonye, "Mechanical Properties of Concrete Incorporating Calcined Ebonyi Shale (CES) at Elevated Temperature," *Key Engineering Materials*, vol. 919, pp. 21–27, 2022, https://doi.org/10.4028/p-n3m2u9.

[18] C. Esonye, A. O. Ogah, E. N. Ikezue, and V. T. Ibeabuchi, "Multi-objectives Statistical Optimization and micro-mechanics Mathematical Modelling of Musa Acuminate fibre-vinyl Ester Composite Reinforcement," *Fibers and Polymers*, vol. 23, no. 11, pp. 3163–3178, Nov. 2022, https://doi.org/10.1007/s12221-022-0280-6.

[19] S. khan, M. N. Nagabhushana, D. Tiwari, and P. K. Jain, "Rutting in Flexible Pavement: An Approach of Evaluation with Accelerated Pavement Testing Facility," *Procedia - Social and Behavioral Sciences*, vol. 104, pp. 149–157, Dec. 2013, https://doi.org/10.1016/j.sbspro.2013.11.107.

[20] S. Varma, H. Sebaaly, J. W. Maina, and A. Al Ghbani, "Experimental investigation of Marshall and Superpave mix design methods for rutting criteria," in *38th Annual Southern African Transport Conference*, Pretoria, South Africa, Jul. 2019, pp. 1–9.

[21] S. S. Almasoudi and A. H. K. Albayati, "Statistical Analysis of Component Deviation from Job Mix Formula in Hot Mix Asphalt," *Engineering, Technology & Applied Science Research*, vol. 12, no. 5, pp. 9295–9301, Oct. 2022, https://doi.org/10.48084/etasr.5225.

[22] Asphalt Institute, *Superpave Mix Design: Superpave Series No. 2*. Kentucky, USA: Asphalt Institute, 2001.

[23] I. M. Asi and Y. Khalayleh, "Adaptation of Superpave Asphalt Concrete Mix Design Procedure to Jordan Climatic and Traffic Conditions," *International Journal of Pavement Research and Technology*, vol. 4, no. 3, pp. 154–161, May 2011, https://doi.org/10.6135/ijprt.org.tw/2011.4(3).154.

[24] T. W. Kennedy *et al.*, *Superior performing asphalt pavements, superpave: the product of the SHRP asphalt research program.* Washington, DC, USA: Strategic Highway Research Program, National Research Council, 1994.

[25] *ASTM C1252-23(2023), Standard Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)*. West Conshohocken, PA, USA: ASTM International, 2023.

[26] J. H. Yousif, H. A. Al-Balushi, H. A. Kazem, and M. T. Chaichan, "Analysis and forecasting of weather conditions in Oman for renewable energy applications," *Case Studies in Thermal Engineering*, vol. 13, Mar. 2019, Art. no. 100355, https://doi.org/10.1016/j.csite.2018.11.006.

[27] *ASTM D 6927-15(2015), Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*. West Conshohocken, PA, USA: ASTM International, 2015.

[28] V. Radhakrishnan, G. S. Chowdari, K. S. Reddy, and R. Chattaraj, "Evaluation of wheel tracking and field rutting susceptibility of dense bituminous mixes," *Road Materials and Pavement Design*, vol. 20, no. 1, pp. 90–109, Jan. 2019, https://doi.org/10.1080/14680629.2017.1374998.