Wadi AlShatti University Journal of
Pure and Applied Science

مجلة جامعة وادي الشاطئ
للعلوم البحتة والتطبيقية

Volume 2, No. 2, July-December 2024 Online ISSN: 3006-0877 المجلد 2، الاصدار 2، يوليو - ديسمبر 2024

CIVIL ENGINEERING

Enhanced Asphalt Mixture Design for Sustainable Pavements

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ARTICLE HISTORY
Received 09 May 2024
Revised 01 June 2024
Accepted 10 June 2024
Online 13 June 2024

KEYWORDS
Asphalt mixture;
Design methods;
Pavement technical performance;
Modelling methods.

ABSTRACT

This study explores ways to improve asphalt mixture design for stronger and more sustainable roads. We examine three common design methods :Marshall, Superpave, and GTM ; to see which one works best. By testing different asphalt mixtures made with these methods, we uncover important differences in performance. Our results show that the GTM method produces asphalt mixtures with fewer voids and lower bitumen aggregate ratios, making them more stable in water and high temperatures. Additionally, GTM mixtures show better stability compared to those made with the Marshall and Superpave methods. While Superpave design results in mixtures with lower bitumen aggregate ratios, they last longer under repeated stress. However, mixtures made with the Marshall method don't perform as well overall. This research provides valuable insights into improving asphalt mixture design to create longer-lasting and more resilient roads.

تصميم خلائط الأسفلت المتقدمة لتحقيق استدامة الأرصفة

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الكلمات المفتاحية
خلائط الأسفلت
طرق التصميم
أداء الأرصفة الفني
طرق التشكيل

الملخص

تستكشف هذه الدراسة طرق تحسين تصميم خلائط الأسفلت لجعل الطرق أقوى وأكثر استدامة. ندرس ثلاث طرق تصميم شائعة: مارشال، سوبر بيف، وجي تي إم؛ لمعرفة أيها يعمل بشكل أفضل. من خلال اختبار خلائط الأسفلت المختلفة المصنوعة بهذه الطرق، نكشف عن اختلافات مهمة في الأداء. تُظهر نتائجنا أن طريقة جي تي إم تنتج خلائط أسفلتية تحتوي على عدد أقل من الفراغات ونسبة أقل من البيتومين إلى الركام، مما يجعلها أكثر استقرارًا في الماء ودرجات الحرارة العالية. بالإضافة إلى ذلك، تظهر خلائط جي تي إم ثباتًا أفضل مقارنةً بتلك المصنوعة بطرق مارشال وسوبر بيف. في حين ينتج تصميم سوبر بيف خلائط بنسب أقل من البيتومين إلى الركام، فإنها تدوم لفترة أطول تحت الإجهاد المتكرر. ومع ذلك، فإن الخلائط المصنوعة بطريقة مارشال لا تؤدي بشكل جيد عمومًا. توفر هذه البحث رؤى قيمة حول تحسين تصميم خلائط الأسفلت لإنشاء طرق تدوم لفترة أطول وأكثر مقاومة.

Introduction

The Foundation of Road Construction

Roads serve as vital arteries in our transportation network, connecting communities and facilitating the movement of people and goods. Ensuring the integrity and longevity of these roadways is paramount to fostering safe and efficient travel. Asphalt, a ubiquitous material in road construction, forms the backbone of many of our highways and streets. Its durability, flexibility, and affordability make it a preferred choice for pavement surfaces.

The Imperative for Improvement

Despite its ubiquity, road construction faces numerous challenges, including heavy traffic loads, adverse weather conditions, and the passage of time. These factors contribute to the degradation of road surfaces, resulting in potholes, cracks, and unevenness. Such deterioration not only diminishes the driving experience but also poses safety hazards to motorists and pedestrians alike. Therefore, continual advancements in road construction techniques and materials are imperative to mitigate these challenges and ensure the longevity and safety of our road infrastructure.

The Crucial Role of Asphalt Mixture Design

At the heart of road construction lies the science of asphalt mixture design. This process involves meticulously selecting the right combination of materials and methods to create asphalt mixtures that meet stringent performance criteria. Asphalt mixture design methodologies, such as the Marshall, Superpave, and GTM methods, play a pivotal role in guiding engineers in this endeavor. By employing these methodologies, engineers can tailor asphalt mixtures to withstand the rigors of heavy traffic and adverse environmental conditions, thereby enhancing the resilience and sustainability of road pavements.

Understanding Design Methodologies:

The Marshall Method, originating in the early 20th century, represents one of the foundational approaches to asphalt mixture design. The Marshall Method is one of the oldest ways to make asphalt mixtures. It's simple: you compact the asphalt with a heavy hammer and see how well it holds up. But sometimes it's not accurate enough to predict how the road will hold up over time [1].

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In contrast, the Superpave Method, introduced in the 1990s, revolutionized asphalt mixture design by incorporating advanced performance tests and mathematical models. By considering factors such as traffic volume, temperature variations, and pavement distresses, the Superpave Method aims to optimize the quality and longevity of asphalt pavements. Its comprehensive approach represents a significant advancement over traditional methods.

The GTM Method, a more recent addition to asphalt mixture design methodologies, prioritizes simplicity and adaptability. By accounting for anticipated traffic volumes and vehicle types, the GTM Method enables engineers to create asphalt mixtures tailored to specific project requirements. Its pragmatic approach offers flexibility and efficiency, making it a valuable tool in modern road construction projects. In the paper, AC-13, AC-20 and AC-25 asphalt mixtures were executed based on Marshall, GTM and Superpave separately, and the performances of asphalt mixture designed by different method were determined and compared.

Both Marshall and Superpave are volume design methods. Superpave mixture design system is the most important part of outcome of SHRP plan. Superpave mixture design includes three design levels: level I, level II and level III [3]. Basically volume design is the Level I, in which the asphalt content and aggregate gradation were decided based on performance of asphalt and aggregate, and volume index of asphalt mixture is also considered. The resistance to water damage of asphalt mixture is performed in level I. Level II and III are mixture design process related to the mechanical properties and pavement performance of asphalt mixture [2,3].

Experimental Data

Materials in Tests:

AC-13:

- Asphalt: SBS
- Aggregate: Basalt
- Mineral Powder: Limestone

AC-20 and AC-25:

- Asphalt: 70#
- Aggregate: Limestone
- Mineral Powder: Limestone

Properties of Materials:

All materials conform to the requirements of "Technical Specification for Construction of Highway Asphalt Pavement" (JTG F40-2004) [4].

Asphalt of SBS

- Grade: I-D
- Density at 15°C: 1.020 g/cm³

70# Asphalt

- Grade: A
- Density at 15°C: 1.037 g/cm³

Limestone Mineral Powder:

- Apparent Density: 2.785 g/cm³

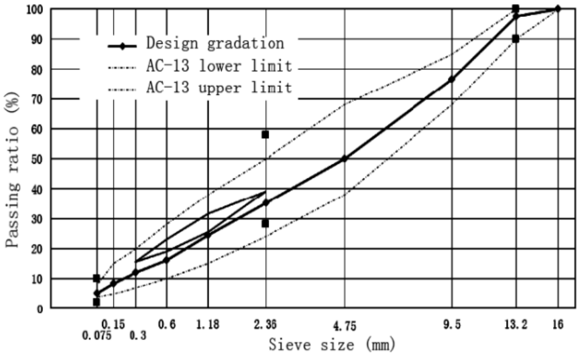
The densities of aggregate are shown in Table1 and Table 2 (JTG E42-2005) [5].

Results and Discussion

Mixture Proportion Design

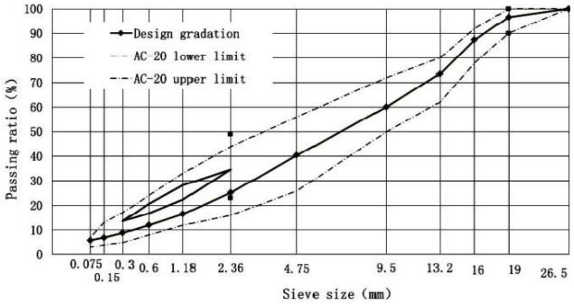
Aggregate Gradation Design:

The research followed the guidelines for aggregate gradation of AC-13, AC-20, and AC-25 asphalt mixtures as outlined in the JTG F40-2004 specifications [1]. The designed mineral aggregate gradations are depicted in Figure 1.



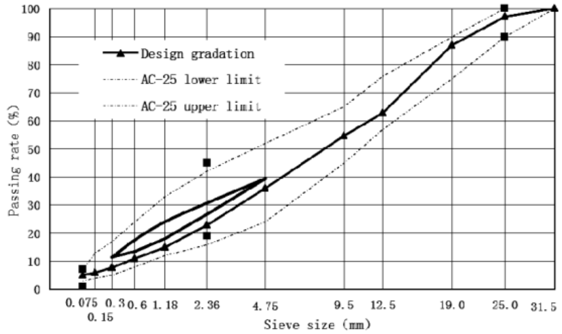
(a)

Fig 1.Aggregate Gradation curves of Ashalt mixtures AC-13



(b)

Fig.1 Aggregate gradation curves of Asphalt mixtures AC-20



(c)

Fig. 1: Aggregate gradation curves of Asphalt mixtures AC-25

Table 1: Density of aggregate test results of AC13

Aggregate group g/cm^3	13.2÷16.0	9.5÷13.2	4.75÷9.5	2.36÷4.75	1.18÷2.36	0.6÷1.18	0.3÷0.6	1.15÷0.3	0.075÷0.15	0÷0.075
Apparent density	2.904	2.871	2.828	2.793	2.773	2.765	2.758	2.749	2.736	2.765
Bulk density	2.889	2.829	2.787	2.701	2.689	-	-	-	-	-

Table 2: Density of aggregate test results of AC20, AC25

Aggregate group g/cm^3	26.5÷31.5	19.0÷26.5	9.5÷19.0	4.75÷9.5	2.36÷4.75	0÷2.36
Apparent density	2.798	2.778	2.784	2.793	2.771	2.703
Bulk density	2.791	2.792	2.751	2.742	2.743	2.662

The Superpave method typically requires selecting three different gradations for optimization, but for consistency in comparison, this study opted for the same gradation as used in Marshall and GTM methods.

Optimum Asphalt Content

The optimal asphalt content for each asphalt mixture type was determined using procedures specified in the Marshall, GTM, and Superpave standards. Table 3 summarizes the results, including the optimum asphalt-aggregate ratio and volume parameters. Variations were observed among the methods, with GTM generally showing the highest bulk density and VFA values, followed by Superpave and Marshall. The order of the methods in terms of optimum asphalt content, porosity, and VMA is GTM < Superpave < Marshall. These differences are attributed to the distinct compacting methods and underlying theories of each design method, which can affect pavement performance.

Table 3: Design results by different design methods

Types	Methods	Optimum asphalt aggregate ratio (%)	Bulk density (g/cm³)	VV (%)	VMA (%)	VFA (%)
AC-13	GTM	4.6	2.526	2.6	12.2	78.5
	Superpave	4.7	2.488	4	13.6	71
	Marshall	5	2.468	4.2	14.6	71.3
AC-20	GTM	4	2.516	2.1	11.5	81.5
	Superpave	4.1	2.469	4	13.1	70
	Marshall	4.5	2.438	4.4	14.5	69.9
AC-25	GTM	3.8	2.494	2.2	11	81.2
	Superpave	3.9	2.479	4.1	13	68.5
	Marshall	4.1	2.453	4.8	13.8	60.5

Performance Test

High Temperature Stability

Indoor rutting experiments were conducted according to JTG E20-2011 standards [2]. Figure 2 illustrates the dynamic stability of asphalt mixtures designed using different methods. Marshall's heavy hammer compaction method, while meeting volume parameter requirements, resulted in lower high temperature stability due to changes in aggregate arrangement under wheel load. GTM specimens, with higher density and lower asphalt content, exhibited better resistance to shear deformation. Superpave specimens, with strict porosity control and SGC compaction method, also showed improved high temperature stability.

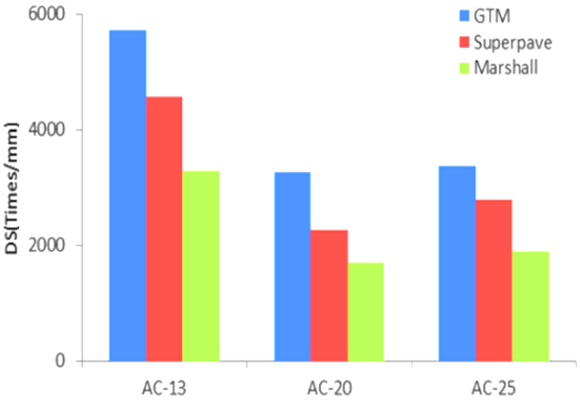


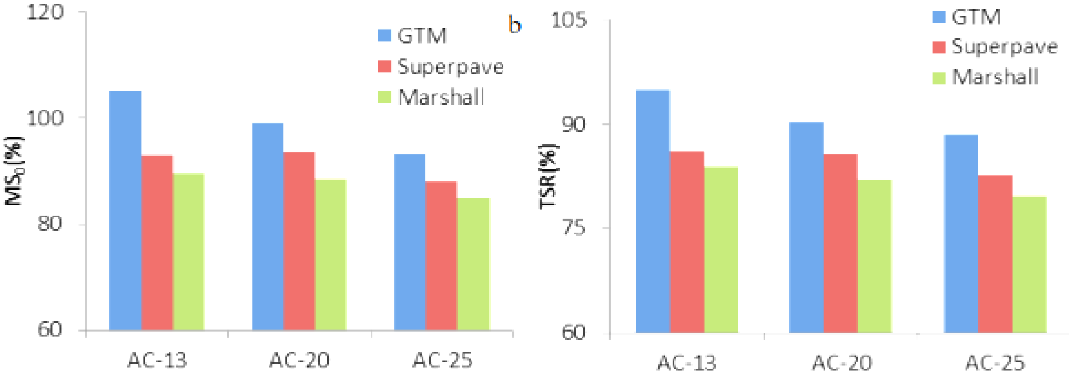
Fig. 2: High temperature stability of Asphalt Mixtures Design.

Anti-Stripping Performance

Residual stability and freeze-thaw splitting tests were conducted to evaluate anti-stripping performance. As shown in Figure 3, GTM specimens demonstrated the highest residual stability, followed by Superpave and Marshall. This indicates better anti-stripping performance in GTM specimens, attributed to their higher density and lower porosity, which reduce water permeability and internal structural impact.

Anti-Fatigue Performance

Fatigue tests were conducted to assess the anti-fatigue performance of asphalt mixtures. Figure 4 presents the fatigue test results, showing that GTM and Superpave specimens exhibited lower porosity but higher asphalt content compared to Marshall. This contributed to higher strength and better resistance to various damages. Marshall specimens, with higher asphalt content and lower VFA, exhibited lower anti-fatigue performance.



(a)

(b)

Fig. 3: Test results

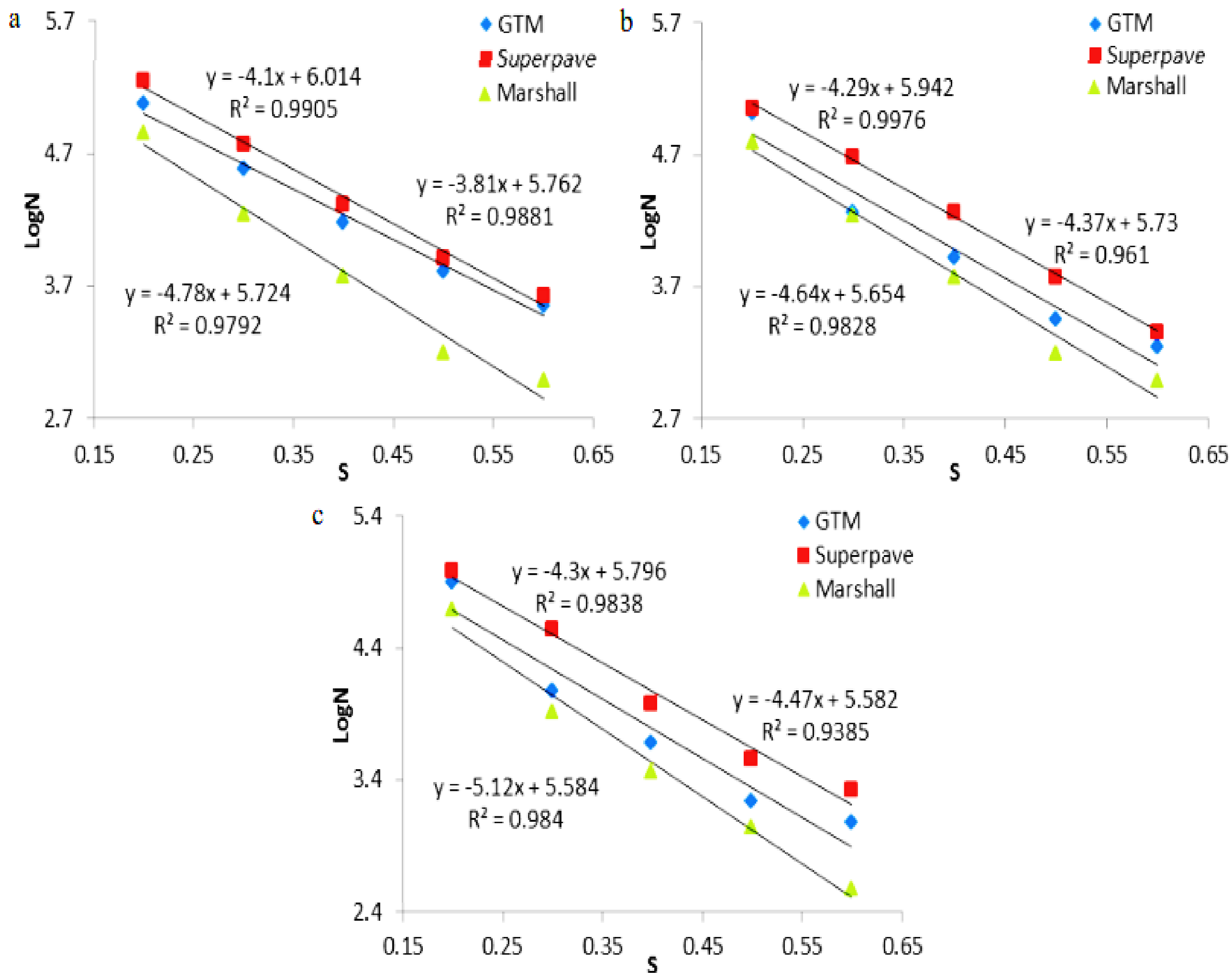


Fig 4: S-N curve of asphalt mixture

Analysis

Despite using the same materials and experimental conditions, differences were observed in the performance of asphalt mixtures designed using different methods. Marshall, GTM, and Superpave methods employ different design principles and specimen production methods, leading to variations in performance. The research suggests that within the scope of this study, GTM and Superpave methods yield better results than Marshall. Therefore, there is a need to reconsider and revise asphalt mixture design methods and quality inspection criteria to improve pavement quality.

Conclusion

In conclusion, this study provided a comprehensive analysis of three prominent design methodologies for asphalt mixtures: Marshall, GTM, and Superpave. Through experimental exploration, significant differences in both the volume parameter of asphalt mixtures and pavement performance were observed among the three methods.

The findings indicate that asphalt mixtures designed using the GTM method exhibited superior technical performance compared to those designed using the Marshall method, with the Superpave method falling somewhere in between. These differences can be attributed to variations in molding methods, emphases, and design principles inherent in each methodology.

The GTM method, which closely aligns with actual conditions and considers the real stress state of pavements, emerged as the most promising approach for optimizing asphalt mixture performance. Therefore, promoting the adoption of this design method could lead to significant improvements in pavement durability and longevity.

In summary, this research underscores the importance of selecting appropriate design methodologies for asphalt mixtures to ensure optimal performance in real-world conditions. Further exploration and promotion of design methods such as GTM are recommended to address current limitations and enhance the technical performance of asphalt pavements.

Author Contributions: “All the work was done by Salem.”
Funding: “This research received no external funding.”
Data Availability Statement: “The data are available at request.”
Acknowledgments: "The authors would like to express their appreciation to all persons and organizations who contributed to the publication of this research paper. I would also like to thank our colleagues at Waddi Alshatti University for their comments and support throughout the research process.

Therefore, I would like to thank them for their valuable opinions and suggestions."

Conflicts of Interest: “The author declares no conflict of interest.”

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