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EVALUATING THE STABILITY OF ASPHALTIC CONCRETE ROAD SURFACES UNDER TEMPERATURE VARIATIONS USING MARSHALL TESTING

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ABSTRACT

Asphalt binder is a thermoplastic material that exhibits elastic, solid-like behaviour at low service temperatures or under rapid loading rates. Conversely, at high temperatures or under slow loading rates, the asphalt binder transitions to a viscous, liquid-like state. This dual behaviour underscores the importance of evaluating the mechanical properties of asphalt concrete at expected service temperatures to mitigate stress cracking and fatigue at lower temperatures and plastic deformation (rutting) at higher temperatures.

In this study, Marshall tests were utilized effectively to analyze the impact of temperature on the mechanical properties of asphalt mixtures. Limestone aggregate, sourced from the Mahroga Crusher, served as the primary material. Seventy-two Marshall samples were prepared using mixtures optimized for bitumen content, as determined by the Marshall test. These mixtures incorporated 60/70 penetration-grade asphalt cement imported from Italy. Stability test results revealed an increase in stability values at temperatures below 60°C (specifically at 50°C and 55°C), while stability values decreased at higher temperatures (such as 65°C and 70°C).

Keywords: Asphalt, Marshall, Stability and Flow, Temperature, Mechanical Properties.

تقييم ثبات الأسطح الخرسانية الإسفلتية للطرق تحت تأثير التغيرات الحرارية باستخدام اختبار مارشال

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الملخص

الرابط الإسفلتي مادة لدنة حرارية تظهر سلوكًا مرنًا صلبًا عند درجات الحرارة المنخفضة أو تحت معدلات التحميل السريعة. في المقابل، عند درجات الحرارة العالية أو تحت معدلات التحميل البطيئة، يتحول الرابط الإسفلتي إلى حالة لزجة سائلة. هذا السلوك المزدوج يؤكد أهمية تقييم الخصائص الميكانيكية للخرسانة الإسفلتية عند درجات حرارة التشغيل المتوقعة لتخفيف تشقق الإجهاد والإجهاد عند درجات الحرارة المنخفضة، وكذلك التشوه اللدن (الإنبعاج) عند درجات الحرارة العالية.

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في هذه الدراسة، تم استخدام اختبارات مارشال بشكل فعال لتحليل تأثير درجة الحرارة على الخصائص الميكانيكية للخلطات الإسفلتية. تم استخدام الركام الحجري الجيري من منشأة كسارة المحروقة كمادة أساسية. تم تحضير 72 عينة مارشال باستخدام خلطات مُحسّنة لمحتوى البيتومين كما حددها اختبار مارشال. تضمنت هذه الخلطات أسمنتًا إسفلتيًا من النوع 70/60 (اختراق) مستوردًا من إيطاليا. أظهرت نتائج اختبار الثبات زيادة في قيم الثبات عند درجات حرارة أقل من 60°م، تحديدًا عند 50°م و55°م، بينما انخفضت قيم الثبات عند درجات الحرارة الأعلى مثل 65°م و70°م..

الكلمات المفتاحية: الإسفلت، ثبات مارشال وجريان، درجة الحرارة، الخصائص الميكانيكية

Introduction

Highway pavement damage primarily occurs in the upper layers, specifically the binding and surface layers. Common distresses, such as thermal cracks, rutting, potholes, and deformation, are often exacerbated by temperature variations. This study evaluates the stability of asphaltic concrete road surfaces under temperature fluctuations using Marshall testing, a critical methodology for assessing asphalt mixture performance.

The stability and flow properties of asphalt concrete are vital for pavement durability. Insufficient stability can lead to premature failures such as rutting (under high temperatures) or cracking (under low temperatures). Previous studies (Tigdemir et al., 2002, 2004) have shown that stability is influenced by factors like bitumen content, aggregate gradation, and climatic conditions. Cooper and Pell (1974) further identified mix stiffness, binder viscosity, and construction practices as key determinants. Fatigue cracking under repetitive loads also remains a major concern (Liang Zhou, 1997).

The Marshall method, a widely adopted laboratory procedure for asphalt design, comprehensively evaluates mixtures through stability, flow, density, and void analysis. Despite its prevalence, few studies systematically correlate Marshall test results (e.g., stability decline at high temperatures or flow variations under prolonged heat exposure) with field performance. This research addresses this gap by statistically analyzing 72 Marshall samples prepared with Libyan limestone aggregate and 60/70 penetration-grade bitumen. Samples were tested at temperatures ranging from 35°C to 75°C to quantify temperature-dependent stability loss and flow changes.

By linking laboratory findings to real-world thermal distress mechanisms, this study aims to optimize asphalt mixtures for temperature resilience, thereby mitigating rutting and thermal cracking in highway pavements.

What are stability and flow?

The Marshall test involves compressing a cylindrical specimen of bituminous material between two semi-circular test heads, recording the maximum load (stability) and the corresponding deformation (flow).

Why is stability important in asphalt pavements?

Stability in hot mix asphalt pavements ensures resistance to shoving and rutting under traffic, helping to maintain shape and smoothness under repeated loads. Adequate stability is crucial to withstand traffic loads without becoming overly stiff, which can compromise durability.

What is the significance of stability and flow values obtained from the Marshall test?

The flow value indicates the vertical deformation of the specimen at the maximum load. Marshall stability reflects the resistance of bituminous materials to distortion, displacement, rutting, and shearing stresses, primarily derived from internal friction and cohesion within the mixture.

Why is it important to conduct Marshall stability tests on asphalt mixtures?

Marshall testing allows engineers to:

- Select appropriate mineral aggregate and binder materials.
- Determine the optimum asphalt content for a mix that maximizes strength and stability.
- Measure the strength and flow characteristics of the mixture through load testing.

What is a critical property of asphalt mixtures?

Stability—the ability to withstand loads—is critical for the durability of asphalt pavements. Tensile, flexural, and flow properties are also essential. Asphalt pavements should be resilient, capable of rebounding after instantaneous loads.

2. MATERIAL CHARACTERIZATION

In this work, aggregate, filler, and asphalt cement were characterized using routine tests. The results were then compared with the specifications of the Libya State Corporation for Roads and Bridges.

2.1 Pure Bitumen 60/70 Properties

In this study, 60/70 penetration grade bitumen sourced from Italy was used as the binder. The properties of the bitumen are shown in Table 1.

Table 1. 60/70 Bitumen Properties and Test Result

Sr No.	Bıtumen Concensus Properties	Units	Test Results
1	Penetration@25°C, 100gr/	0.01mm	62
2	Softening Point	°C	51,5
3	Density @25C	Kg/L	1,038
4	Duktility@25C	Cm	100+
5	Flash -Firepoint	°C	310-330

2.2 Aggregate

The quality of aggregates is crucial to the performance of asphalt mixtures, as they constitute 80% to 85% of the mixture by volume. Aggregate characteristics significantly influence asphalt mixture performance. The Superpave mixture design system incorporates numerous aggregate criteria to ensure the optimal performance of asphalt mixtures.

Research indicates that mixture stability improves with an increased proportion of crushed particles replacing rounded gravels and sands. Brown and Cross (1992) conducted a comprehensive study on material properties and their correlation with pavement performance, examining 42 pavements across 14 states. Their analysis included rut depth measurements, mix design data, construction records, traffic counts, and pavement samples.

Rounded aggregates provide minimal interlocking, potentially leading to movement within the hot mix asphalt. To mitigate this, asphalt specifications often recommend increasing the proportion of fractured aggregate surfaces as traffic volumes increase. While the specific values may not be universally validated, they align with historical practices. Generally, increasing fractured surfaces enhances the Voids in Mineral Aggregate (VMA), thereby improving durability and stability.

The tests performed in accordance with Astm Standards are as follows:

- Course and Fine Aggregate Angularity Test
- Flat and Elongated Test
- Los Angeles Abrasion Resistance Test
- Soundness Of Aggregate Sodium Sulfate Test
- Clay Lumps Test For Aggregates
- Sand Equıvalent Test Fine Aggregate
- Specific Gravity Test For of Aggregates
- Crushing Aggregate Test
- Impact Value Test
- Atterberg Limits Test

Table2. Mahroga Crusher Plant Aggregate Test Results

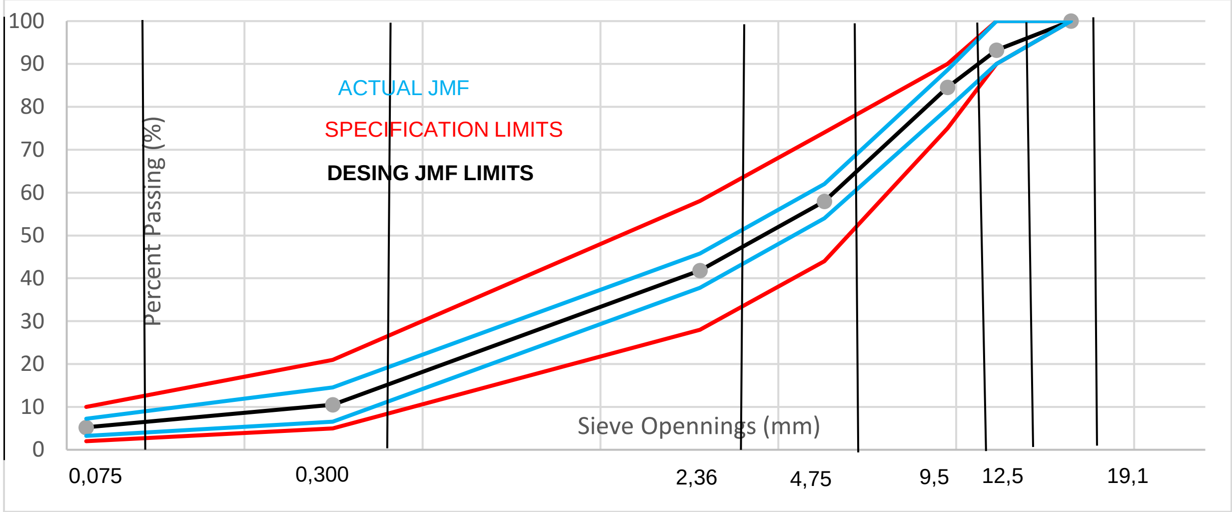
Sr No. (%)	Aggregate Concensus Properties	Test Results (%)	Criteria
1	Course Aggregate Angularity	99.7	90/95 min.
2	Fine Aggregate Angularity	62,4	45 min.
3	Los Angeles Abrasion Resistance Test	19,6	30 max.
4	Soundness Of Aggregate Sodium Sulfate Test	0.886	18 max.
5	Clay Lumps Test For Aggregates	12.6	25 max.
6	Sand Equıvalent Test Fine Aggregate	80.6	45 min.
7	Crushin Aggregate Test	100	95 min.
8	Impact Value Test	8.20	20 max
9	Atterberg Limits Test	Non-Plastic	N.P
10	Specific Gravity Test Results		

Property	Aggregate Fraction /Mahroga			
	0-3	3-8	8-11	11-19
Bulk specific gravity	2,574	2,588	2,611	2,600
Saturated surface dry S.G	2,624	2,636	2,658	2,642
Apparent S.G	2,709	2,720	2,739	2,716
Absorption %	1,93	1,87	1,78	1,65

In this study, crushed limestone was extracted from the Mahroga quarry. This aggregate was graded in accordance with ASTM standards and combined in appropriate proportions.

Table3. Aggregate gradation curve.

	SIEVES		**MIX DESIGN**	**SPECIFICATION LIMITS ASTM D 3515**		**DESING JMF LIMITS**		Mahroga Gradation	
ITEM	**inch**	**mm**		**Min.**	**Max.**	**Min.**	**Max.**		
1	**3/4"**	**19,0**	**100,0**	100	100	100	100		
2	**1/2"**	**12,5**	**93,3**	90	100	90	100	**Material**	**% Use**
3	**3/8"**	**9,5**	**84,6**	75	90	77,6	90	Agg. Size 11/19 mm.	10
4	**No:4**	**4,75**	**58,0**	44	74	51,0	65,0	Agg. Size 8/11 mm.	22
5	**No:8**	**2,36**	**41,8**	28	58	35,8	47,8	Agg. Size 3/8 mm.	23
6	**No:50**	**0,300**	**10,5**	5	21	5,5	15,5	Agg. Size 0/3 mm.	45
7	**No:200**	**0,075**	**5,2**	2	10	2,2	8,2	**TOTAL**	**100**
8	**BITUMEN**		**5,80**	±0,3		**5,50**	**6,10**		



2.3 Marshall Mixture Dizayn

The mix design was achieved by adding bitumen to the aggregate blend, ensuring the gradation complied with the specified limits determined through preliminary studies.

Table 4. Summary Table of Asphalt Design Results

ITEM	**Description**	**UNIT**	**Mahroga Aggregate Mix Dizayn**	**SPECIFICATION**
1	NO.Of Blows	No	**2 x 75.**	2 x 75.
2	Bitümen Content By Mix	%	**5,80**	3.5-6.0
3	Bulk Density	g/cm3	**2,346**	-
4	Stability	kg.	**1480**	Min.816
5	Flow	mm.	**2,98**	2-4
6	Gmm	g/cm3	**2,447**	-
7	Air Voids	%	**4,12**	3-5
8	Voids Filled by Bitumen	%	**71,36**	65 - 75
9	Voids in Mineral Aggregates	%	**14,37**	min. 14

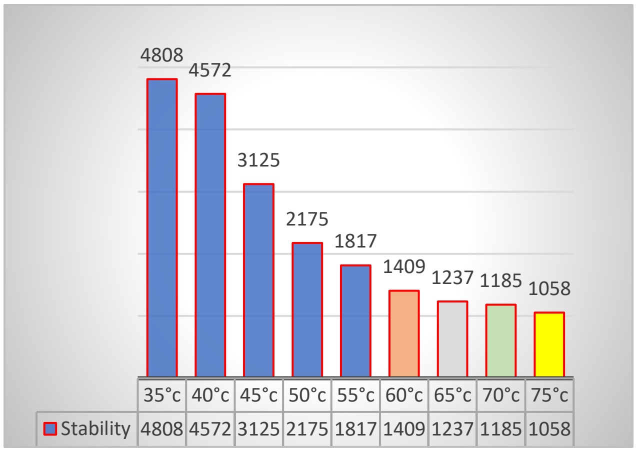
ITEM	**Description**	**UNIT**	**Mahroga Aggregate Mix Dizayn**	**SPECIFICATION**
10	% Fıller / % Efectıve Asph. Content	%	**1,140**	0,6 - 1,2
11	TSR	kg.	**85,35**	min. 80
12	Wheel Rutting	mm	**2,70**	≤4.5mm 20.000 Number Of Passed

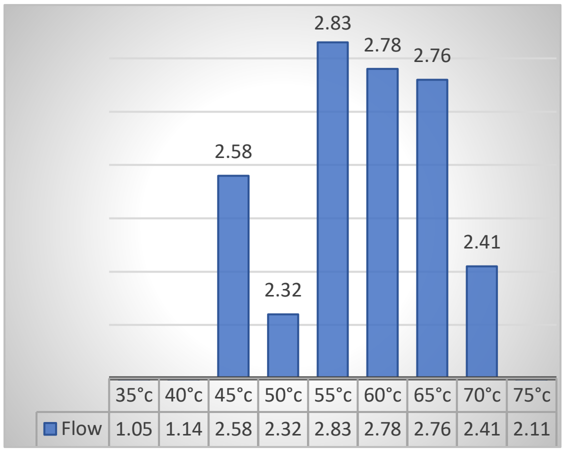
3. EXPERIMENTAL STUDY

Thirty-six Marshall specimens were prepared according to standard asphalt mixture design procedures, and the mixture gradation and optimum bitumen content were determined. The prepared specimens were then immersed in water baths at temperatures of 35°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, and 70°C for 30 to 40 minutes each. Subsequently, stability and flow tests were performed using an automated Marshall testing machine.

Table 5. Summary Table of Marshall Test Results

ITEM	**Temprature°C**	**UNIT**	**STABILITY kf**	**FLOW mm**
1	35°C	Kf-mm	**4808**	1.05
2	40°C	Kf-mm	**4572**	1.14
3	45°C	Kf-mm	**3125**	2.58
4	50°C	Kf-mm	**2175**	2.32
5	55°C	Kf-mm	**1817**	2.83
6	60°C	Kf-mm	**1409**	2.78
7	65°C	Kf-mm	**1237**	2.76
8	70°C	Kf-mm	**1185**	2.42
9	75°C	Kf-mm	**1058**	2.11





Practical Recommendations

The Marshall stability and flow test results (Table 5) offer valuable insights into the performance of asphalt concrete at different temperatures. The key practical implications derived from these data are discussed below:

1. Temperature-Dependent Stability Loss

- High Stability at Lower Temperatures (35–50°C):

- Stability values were 3.4 times greater at 35°C (4808 kgf) compared to the standard 60°C test (1409 kgf).
- Recommendation: In cooler climates (below 50°C), conventional asphalt mixes may perform adequately without modification.

• Significant Decline Above 55°C:

- Stability decreased by 24.9% at 75°C compared to 60°C, indicating thermal susceptibility.
- Recommendation: In high-temperature regions (e.g., the Libyan Desert), consider using polymer-modified bitumen (PMB) or crumb rubber modifiers to improve rutting resistance.

2. Flow Behavior and Pavement Durability

Flow Reduction at High Temperatures:

- Flow decreased from 2.83 mm (at 55°C) to 2.11 mm (at 75°C), remaining within typical limits (2–4 mm).
- Implication: Although flow is less sensitive to temperature than stability, the potential for brittleness above 70°C should be considered.
- Recommendation: Optimize bitumen content to balance flexibility and stability (e.g., 4.5–5.5% by weight for 60/70 penetration grade bitumen).

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3. Critical Temperature Thresholds for Design

- **60°C as a Key Performance Indicator:**
    - The 12.2% stability loss at 60°C (compared to 55°C) suggests this temperature is a critical threshold for performance.
    - Recommendation: Revise local mix design standards (e.g., Libyan specifications) to prioritize performance testing at 60°C and 70°C, especially for high-traffic areas.
- **Peak Heat Vulnerability (70–75°C):**
    - Stability at 75°C was 24.9% lower than at 60°C, indicating a significant risk of rutting.
    - Recommendation: Consider implementing cool pavement technologies (e.g., reflective coatings) in urban areas to reduce pavement surface temperatures.

4. Construction and Maintenance Strategies

- Traffic Management:
    - Consider restricting heavy vehicle traffic during peak heat hours (12:00–15:00) to minimize shear stresses.
- Layer Thickness Adjustment:
    - In high-temperature zones, consider increasing the binder course thickness by 15–20% to improve load distribution.
- Preventive Maintenance:
    - Apply crack sealants before the onset of summer to mitigate thermal fatigue cracking.

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5. Future Research Directions

- Field Validation: Conduct in-situ highway testing to correlate laboratory results with real-world performance.
- Advanced Materials: Investigate nanoclay-modified bitumen for improved thermal stability.

Data-Driven Action Items:

- For Libya: Implement PMB in asphalt mixes for roads where surface temperatures exceed 60°C.
- For Global Applications: Revise standard asphalt testing protocols to include performance evaluations at 55°C, 60°C, and 70°C.

Scientific Justification

- The data indicate 180.1% greater stability at 35–50°C compared to 60°C, confirming that standard 60°C testing may underestimate asphalt mix performance in cooler climates.

- The observed 24.9% stability loss at 75°C is consistent with the viscoelastic behavior of bitumen at elevated temperatures, supporting the use of PMB (Huang et al., 2021).

- Given that flow values remain within specified limits, the current aggregate gradation appears adequate; however, binder modification may be necessary to enhance performance (AASHTO T 245).

Implementation Example: Libyan Highways

- Daytime Traffic Management: During peak heat hours (12:00–15:00), consider reducing the speed limit for heavy trucks to below 45 km/h to minimize shear stresses on the pavement.
- Asphalt Mix Design: In desert regions (e.g., Brak), increase the thickness of the binder course by 20% and utilize PMB 76-22 in the asphalt mix.

RESULTS AND DISCUSSION

Analysis of asphalt core samples revealed that stability at temperatures between 35°C and 50°C was 180.1% greater than the stability measured at the standard 60°C testing temperature. At 55°C, stability remained 28.96% higher than at 60°C. However, stability decreased markedly at 65°C, 70°C, and 75°C. Specifically, a 12.2% reduction in stability was observed at 60°C, followed by a 15.9% reduction at 70°C, and a 24.9% reduction at 75°C. All samples were conditioned in a water bath at the specified temperature for 30 minutes prior to testing. This trend is consistent with the increased ductility and decreased viscosity of bitumen at elevated temperatures, leading to increased fluidity and reduced resistance to deformation.

Flow values decreased consistently with increasing temperature, but remained within specified limits. This highlights the sensitivity of asphalt mix stability to temperature variations.

The findings indicate that prolonged exposure to elevated temperatures significantly reduces the stability of asphalt concrete, even under constant applied load. This suggests that vehicles of equivalent weight can induce varying stress levels on asphalt pavements depending on the time of day, with peak heat hours posing the greatest risk.

It is important to acknowledge that, in contrast to the uniformly heated laboratory samples used in this study, highway pavements experience a temperature gradient, with only the surface layer of asphalt concrete directly exposed to solar radiation. Therefore, a comprehensive understanding of thermal effects on highways requires investigation into the temperature distribution and its impact on the structural integrity of lower asphalt layers. Such insights can inform the selection of optimal binder properties and layer thicknesses to enhance asphalt concrete stability and mitigate distresses such as rutting, cracking, and depressions.

Conclusion

This study evaluated the stability and flow properties of asphalt concrete under varying temperatures using Marshall testing, focusing on mixtures incorporating Libyan limestone aggregate and 60/70 penetration-grade bitumen.

The findings underscore the significant impact of temperature on asphalt pavement performance, highlighting the need for region-specific design adaptations. Integrating binder modifications, optimized aggregate gradation, and proactive maintenance strategies can substantially improve pavement longevity in thermally challenging environments. These insights are particularly relevant for Libya and other regions with similar climates, where high temperatures accelerate pavement deterioration.

Therefore, it is recommended to revise local standards to prioritize high-temperature performance testing (e.g., at 70°C) and to mandate the use of Polymer Modified Bitumen (PMB) in asphalt mix designs for roads subjected to extreme heat.

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