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CIVIL ENGINEERING

Rubber-Modified Asphalt for Enhanced Performance in Extreme Heat

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ABSTRACT

The quality of bitumen, a critical constituent of asphalt mixtures, is significantly influenced by its chemical composition and production process. Libya's extensive road network, much of which lies in desert areas, suffers from rutting and cracking due to extreme temperature variations. This study aims to enhance asphalt properties by adding rubber. A comprehensive test program, conducted according to German and European standards, demonstrated that rubber-modified asphalt exhibits improved high-temperature stability, low-temperature behavior, and bonding capacity. Specifically, rubber-modified asphalt showed a 7% increase in stability and a 46% reduction in rutting depth compared to conventional asphalt. The improved resistance to water and cracking further validates the efficacy of rubber modification in asphalt.

الأسفلت المعدل بالمطاط لتحسين الأداء في الحرارة الشديدة

حسن عويدات سالم[1]

الكلمات المفتاحية
أسفلت، مطاط
استقرار
فراغ
بيتومين
جهاز ضغط الأسطوانة

الملخص

جودة البيتومين، وهو عنصر أساسي في خلائط الأسفلت، تتأثر بشكل كبير بتكوينه الكيميائي وعملية إنتاجه .شبكة الطرق الواسعة في ليبيا، التي تقع معظمها في المناطق الصحراوية، تعاني من التمدد والتشققات بسبب التغيرات الحرارية الشديدة .تهدف هذه الدراسة إلى تحسين خصائص الأسفلت بإضافة المطاط .برنامج اختبار شامل، تم إجراؤه وفقًا للمعايير الألمانية والأوروبية، أظهر أن الأسفلت المعدل بالمطاط يتمتع بثبات محسّن في درجات الحرارة العالية، وسلوك محسّن في درجات الحرارة المنخفضة، وقدرة ربط محسنة .بشكل محدد، أظهر الأسفلت المعدل بالمطاط زيادة بنسبة 7%في الاستقرار وتقليل بنسبة 46%في عمق التمدد مقارنة بالأسفلت التقليدي .المقاومة المحسّنة للماء والتشققات تعزز فعالية تعديل الأسفلت بالمطاط..

Introduction

Pavement technology research is a global focus, aiming to enhance the performance of various pavement layers and provide cost-effective solutions for road agencies [1,2]. One of the successful outcomes of this research is the development of polymer-modified bitumens (PmB), which effectively address the challenges posed by increasing traffic volumes and loads. PmBs are now widely used worldwide due to their superior performance. However, the high costs associated with the additives used in the manufacturing process pose a drawback. To tackle this issue, many countries have turned to crumb rubber bitumen (CRM), also known as rubber-modified bitumen (RmB). Utilizing discarded vehicle tires, RmB offers similar performance to PmBs but at a lower cost and contributes to sustainability efforts by addressing the global problem of tire disposal. By incorporating RmB into high-performance road construction materials, we can help eliminate this environmental issue. This paper presents a study that assesses the performance of chemically stabilized RmB and compares it with control binders such as plain bitumen and PmB. Recent studies [3,4] have demonstrated the significant benefits of using rubber in asphalt mixtures, particularly in enhancing high-temperature stability and low-temperature flexibility.

Recent studies have highlighted the benefits of rubber-modified asphalt in improving pavement performance. Chen et al.showed significant improvements in high-temperature stability and low-temperature flexibility [3]. Similarly, Zhang et al. highlighted the environmental and economic benefits of using recycled rubber in road construction [4]. Xiao et al. demonstrated improved resistance to rutting and cracking [5]. While Ghabchi et al. emphasized sustainability through the recycling of waste tires [6]. Despite these advances, there is limited research on the performance of rubber-modified asphalt in hot arid regions, which this study aims to address. Kumar et al. found that rubber-modified asphalt enhances pavement performance in high-temperature environments, reducing rutting and thermal

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cracking [7]. Williams and Jones emphasized the alignment of using recycled rubber with sustainability goals [8]. This research builds on these findings by investigating the performance of rubber-modified asphalt mixtures in hot arid regions, thereby filling a critical gap in existing knowledge.

Methodology

A trial section with rubber-modified asphalt was carried out in Brack, Libya. The asphalt was prepared in an asphalt plant, with samples taken from both modified and unmodified asphalt for testing. Xiao, et al. Showed the Performance of Rubberized Asphalt Mixtures in Wet and Dry Conditions [5].

The properties of the modified asphalt were evaluated through a comparative study with normal bitumen, focusing on stability, high and low-temperature behavior, and water resistance. The following standardized test methods for hot asphalt were used:

1**. Marshall Test (EN 12697-30):** Stability, flow, and Marshall Quotient values were determined (Fig. 1).

2**. Wheel Tracking Test (EN 12697-22):** Assessed the susceptibility to deformation under load (Fig. 2-a, b).

3. **Water Sensitivity Test (EN 12697-12):** Evaluated bonding and stripping properties (Fig. 3).

4**. Three-Point Bending Test (EN 12697-44):** Analyzed crack propagation and low-temperature behavior (Fig. 4).

The specimens were prepared in accordance with EN 12697-33 using a slab compactor, ensuring consistency with field conditions.

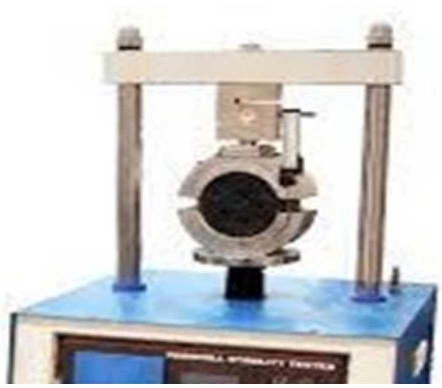
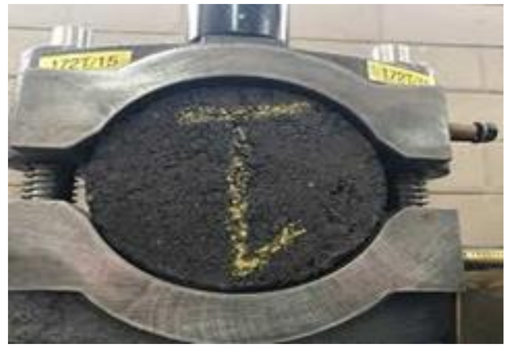


Fig. 1: Marshall-test EN 12697-30: Stability, flow and Marshall Quotient value

(a)



(b)

Fig. 2: Wheel Tracking Test EN 12697-22, (a) Wheel tracking and (b) Susceptibility to deform under load

Fig. 3: Water Sensitivity Test EN 12697-12, Water sensitivity, bonding and stripping

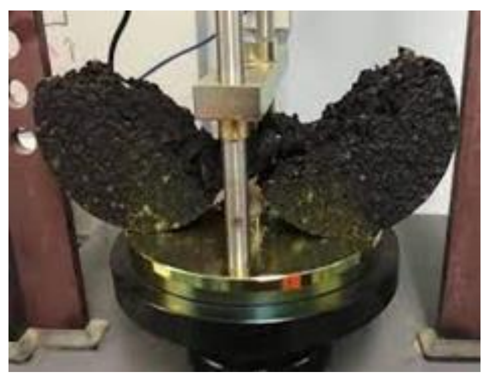


Fig. 4: Three-point-bending-test, EN 12697-44, crack propagation, low temperature behavior

The cores that had been taken out of the trial-section in Brack were also examined according to EN 12697-6 and 8, density and voids content. The specimen for the wheel tracking test and the 3-point-bending test were prepared according to EN 12697-33 Slab Compactor. All tests were carried out with specimens from asphalt mixed in the laboratory and specimens prepared with asphalt from the asphalt plant in Libya. To validate these improvements, a comparative study with both, usual asphalt concrete (AC) and Rubber-modified asphalt concrete was executed. Federal Highway Administration (FHWA) [9].

Table 1: Properties of the specimen, prepared with asphalt from Libya

Mix	Specimen Nr.	Bulk density gm/cm^3	Void content %	Average values gm/cm^3	Density void %
AcLab with 60/70	1	2.322	3.9	2.341	4.2
	2	2.317	4.5		
	3	2.352	4.1		
	4	2.341	3.8		
	5	2.369	4.2		
	6	2.345	3.7		
	Slap	2.341	5.2		
AcLab with Rubber	1	2.329	3.9	2.349	4.0
	2	2.330	4.1		
	3	2.311	4.2		
	4	2.353	3.8		
	5	2.335	4.3		
	6	2.325	3.7		
	Slap	2.46	4.0		

Specimen preparation

Laboratory Preparation

The asphalt mix design was following the specification of the one that is used in Libya as it illustrated in Fig. 5. The bitumen was a penetration grade bitumen 60/70. The binder content was 5 % by weight. Abed et al. showed the Thermo-rheological analysis of WMA-additive modified binders [10].

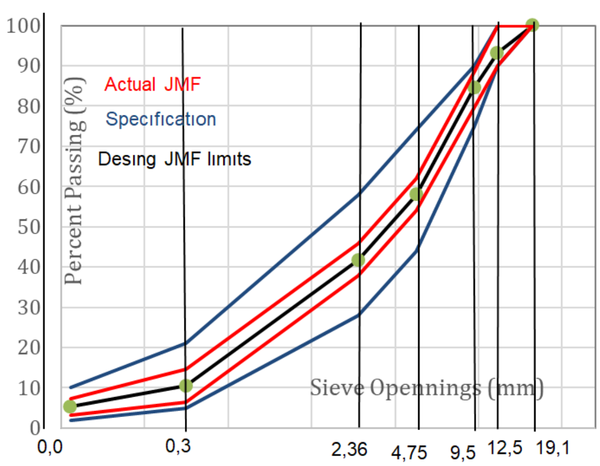


Fig. 5: Particle size distribution of Libyan-mix-design

For the fabrication of the asphalt mixes, a laboratory mixer (according to DIN EN 12697-35 (Bituminous mixtures-test methods for hot mix asphalt-part 35: laboratory mixing) was used. After mixing at a temperature of 170 C, Marshall-specimen and specimen (slabs) according to DIN EN 12697-35 (bituminous mixtures - Test methods for hot mix asphalt - part 33: Specimen prepared by roller compactor) were prepared. With this equipment it is possible to produce specimens in the laboratory with nearly similar properties than the one of asphalt layers on the road.

The properties of the specimen are listed in Table 1, which compares the density and the percentage void content of the two types of asphalt. As it can be seen, the result of the laboratory preparation is dense asphalt concrete as it is recommended by the standards and generally accepted technical rules.

As can be seen, the non-modified and the Rubber-modified specimen have comparable properties regarding their composition. That means that the main reasons for differences in the test results can be seen in the different binders. The mix-design demands a filler content of 8% by mass, which both asphalt-samples do not reach. Due to this lack of filler, the compact ability of both the asphalts is poor. The void content is too high compared to the laboratory prepared asphalt; the void content of the Libyan non modified asphalt is nearly twice the value. The void content of the Rubber-modified specimen made from the Libyan asphalt is about third times higher compared to the laboratory mix.

Moreover, the non-modified and Rubber-modified specimens have different levels of compaction. The reason is to be found in the different amounts of filler in two types of asphalt. The non-modified asphalt has a filler content of 6, 1% by mass, while the Rubber-modified asphalt has only an amount of 3,7% by mass. Ahmed, and Ali have demonstrated the significant benefits of using rubber in asphalt mixtures, Crumb Rubber in Asphalt: Benefits and Challenges [11].

At this point, it has to be stated, that the non-modified and the Rubber-modified specimen have non-comparable properties regarding their composition and level of compaction. That means, the test results will be affected mainly by the void contend and not, as it should be in a comparative study, by the different bituminous binders. This important precondition has to be kept in mind when drawing the conclusions from the test results. Zhang, and Wang showed the Performance of Polymer-Modified Asphalt in Various Climates [12].

Results

Laboratory Preparation

All tests were conducted according to the European Standards.

Marshall test on AC lab

Table 2 shows the stability and the flow-value of the Marshall specimen prepared with non-modified and Rubber asphalt in the laboratory. The use of Rubber increases the stability of the asphalt. The increase is about 7%.

Wheel tracking test on AC lab

Table 3 shows the rut depth after 10.000/20.000 passes with a rubberized wheel in air at 60 °C of specimen prepared with non-modified and Rubber-modified asphalt in the laboratory (one cycle means two Passes).

The use of Rubber decreases the susceptibility to deform under load. The rutting depth of Rubber-modified asphalt reaches only values of about 54% of the non-modified asphalt

Table 2: Stability and the flow-value of the Marshall specimen from laboratory prepared asphalt

Mix	Specimen Nr	Stability kN	Flow mm	Average values Stability kN	Average values Flow mm
ACLab with 60/70	1	16.20	3.40	15.93	3.30
	2	15.66	3.20		
ACLab with Rubber	1	17.10	3.35	17.06	3.39
	2	17.02	3.43		

Water Sensitivity of AC Lab

In Table 4 the results of the Indirect Tensile Strength Ratio (ITSR) with Indirect Tensile Test (ITS) before (d=dry group) and after conditioning in water (w wet group) are shown.

Table 3: Result of the Wheel Tracking test, rutting depth of laboratory prepared asphalt

Mix	Rutting depth after 10.000 passes; mm	Rutting depth after 20.00 passes; mm
AC Lab with 60/70	6.4	8.6
AC Lab with Rubber	3.8	4.7

The (indirect) tensile strength of the Rubber-modified specimen before water conditioning is significantly higher (about 10%). That means the resistance against cracking is improved. The decrease of the tensile strength of Rubber-modified specimen after water storage is lower than in the non-modified asphalt.

Table 4: Result of the water sensitivity test on laboratory prepared asphalt specimen

Mix	Specimen Nr.	ITSd dry group kPa.	ITSd wet group kPa.	ITSR Average %
AC Lab with 60/70	3,4,5,6	3,010 2,367	2,289 2,280	72.8
AC Lab with Rubber	3,4,5,6	3,482 3,443	2,082 2,756	80

The (indirect) tensile strength of the Rubber-modified specimen after water storage is about 20% higher than the one of one of the non-modified asphalts, what means, that the adhesion between the Rubber-modified bitumen and the aggregates is stronger than the adhesion of non-modified bitumen. The penetration of the water molecules between the film of modified bitumen and the aggregate surface is hindered by the stronger bonding strength. The use of Rubber improves the sensitivity against water and enhances the resistance to cracking.

Three-point-bending-test on AC lab

Table 5 is showing the results of the 3-Point-Bending-Test. Measured was the force and the displacement on a 150 mm diameter haft-core at a temperature of 0 °C. According to prEN 12697-44, the horizontal stress Chor and maximum strain Emax are calculated.

The tensile strength of the Rubber-modified specimen is about 26% higher than the tensile strength of the non-modified specimen. That means that the safety against cracking is significantly enhanced. The use of Rubber improves the low temperature behavior and safety against low temperature cracking.

Table 5: Results of the Three-point-bending-test on laboratory prepared asphalt specimen

Mix	Specimen; Half-cores from slab Nr	$\varepsilon\ max$ %	$\sigma\ hor$ N/mm	Average strain $\varepsilon\ max$ %	Average stress $\boldsymbol{\sigma\ hor}$ N/mm²
AC Lab with 60/70	1	8.0	8.87		8.99
	2	6.7	9.1	0.73	
AC Lab with Rubber	1	10.5	11.8		11.35
	2	8.5	10.9	0.93	

Conclusions

To show the improvement of asphalt properties by using Rubber for modifying asphalt, different tests were carried out according to German and European, and the results with Rubber modified laboratory mixed asphalt show certain benefits compared to the standard asphalt, including increased high temperature stability, improved low temperature behavior and increased bonding capacity of the Rubber-modified asphalt. The laboratory compacted specimen had a high void content nearly compensated for the benefits of the Rubber-modification. Despite the high void content, the stability of the Rubber modified asphalt raised for 25% and the rutting depth lowered for 20%. The indirect tensile strength and tensile strength in the 3-Point-Bending-Test with the Rubber modified specimen reached nearly the same values as the non-modified specimen. Thus, the modification with Rubber enhances the properties of asphalt in the high and low temperature range, improves stability and cracking susceptibility and ameliorates the water susceptibility. Even in insufficient compacted asphalt the Rubber-modification has great benefits that can be shown in laboratory tests. The enhanced bonding capacity and the higher viscosity keeps the properties of asphalt with nearly 9% of void content on the level of asphalt with about 6% of voids.

Recommendations

Provided that the mix design is suitable and laying and compacting are adequate, the Rubber-modified gives a high-quality, long-lasting asphalt which satisfies the special demands of a road in a desert climate, with the ability to compensate unavoidable deviations in materials, preparation, laying and compaction of the asphalt. Consequently, we recommend the use of Rubber to enhance the quality of asphalt for desert roads.

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

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