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Comparison between Rubber-Silicon and Polyethylene as an Additive to Hot Mix Asphalt Design

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Abstract To prevent asphalt pavement distresses there are various solutions such as adopting new mix designs or utilization of asphalt additives. The primary aim of this study was to investigate the effect of adding rubber-silicon and Polyethylene Therephthalate (PET) waste bottles as an additive to dense-graded mixture performance properties. This study investigated the essential aspects of modified asphalt mixtures in order to better understand the influence of rubber-silicon and polyethylene modifiers on volumetric and mechanical properties of dense-graded Hot Mix Asphalt (HMA). Marshal mix design was carried out for different type of asphalt binder to determine the different mix design characteristics. In this study three asphalt content were used: virgin bitumen 60/70 penetration grade, bitumen 60/70 added 4% rubber-silicon and bitumen 60/70 added 8% (PET) by weight of the bitumen content. The optimum Asphalt content (OAC) of a mixtures were found to be 4.91 % for HMA modified by rubber-silicon, 5.17% for HMA modified by (PET) and 5.21% for HMA modified by virgin bitumen 60/70 without additive.

Keywords: Hot Mix Asphalt, Polyethylene Therephthalate, Rubber-Silicon, Marshal Mix Design.

مقارنة بين المطاط السيليكونى والبولي إيثيلين كمضافات لتصميم الخلطات الأسفلتية الساخنة

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الملخص لمنع التشوهات الحاصلة على الأرصفة الأسفلتية ، توجد عدة حلول مثل تبني تصاميم جديدة للخلطات الإسفلتية أو استخدام المضافات. كان الهدف الرئيسي من هذه الدراسة هو دراسة تأثير إضافة مخلفات القناني البلاستكىة البولي إيثيلين (PET) والمطاط السيليكونى كمواد مضافة على خواص أداء الخلطات الأسفلتىة الساخنة (HMA) ذات التدرج الحبيبي الكثيف. تبحث هذه الدراسة في الجوانب الأساسية للخلطات الأسفلتىة المعدلة من أجل فهم أفضل لتأثير معدّلات المطاط السيليكونى والبولي إيثيلين على الخواص الحجمية والميكانيكية للخلطات الأسفلتىة الساخنة (HMA). تم إجراء تصميم مارشال للخلطات الأسفلتىة بأنواع مختلفة من رابط الأسفلت لتحديد خصائص التصميم المختلفة. في هذه الدراسة ، تم استخدام ثلاثة أنواع مختلفة من رابط الأسفلت: البيتومين البكر 70/60 ، البيتومين 70/60 المضاف اليه نسبة 4 ٪ من المطاط السيليكونى ، و البيتومين 70/60 المضاف اليه نسبة 8 ٪ من (PET) وذلك من وزن محتوى البيتومين البكر فى الخلطة الاسفلتية. تم الحصول على المحتوى الأمثل للإسفلت (OAC) للخلطات الاسفلتية بنسبة 4.91٪ لـــ HMA المعدلة بواسطة المطاط السيليكونى و 5.17٪ لـــ HMA المعدلة بواسطة (PET) و 5.17٪ للـــ HMA مع البيتومين البكر 70/60 بدون إضافات.

الكلمات المفتاحية: الخلطات الأسفلتىة الساخنة، محتوى الأسفلت الأمثل، المطاط السيليكونى، البولي إيثيلين.

1. Introduction

Distress in flexible pavements are amongst the most important problems encountered on highway construction and operation. The main reasons for the distress are excessive traffic loads and environmental conditions such as the temperature change or exposure to water. These factors shorten the service life of the highways which is undesirable for both the users and administrators of the highways. the rapid increase in traffic intensity, the effect of temperature change on pavement and effect of heavy rain on pavement have put us in a situation to think about some alternate ways for the improvement of pavement quality and characteristics by using a material which satisfies both aspects, strength and economical. To improve the quality there are several measures which are proven to be effective, like investing adequate funds for maintenance of pavement, improved and effective pavement design, use of better quality of materials and modern and effective construction techniques.

Several methods have been implemented in order to prevent and control the various distress in flexible pavements. One method is to modify the bituminous mixtures used in the pavements. Various additives can be used for the modification process. Either the aggregate or the bitumen in the mixture can be modified according to the distortion problem faced. Michele Porto., et al. (2019) Review of the latest papers in the literatures related to modified bituminous materials, technologies, and advances. The authors classified the modifiers and additives have been used to improvement bitumen performance into: polymers, chemical modifiers, extenders, oxidants and antioxidants, hydrocarbons, and anti-stripping additives [1]. Furthermore, Polyethylene Therephthalate (PET) which polymers are categories as *Thermoplastics Polymers*. Likewise, rubber-silicon is polymers and groups to *Synthetic Rubber* material.

The use of rubber and Polyethylene in the modification of hot mix asphalt has an important place in the solution to problems encountered in pavements. There are many studies in the literature to determine the positive and negative effects of rubber and Polyethylene in mixtures. Not only the type, but also the amount of the additive, has an effect on the mixture [2, 3]. Using plastic waste in mix will help reduction in need of bitumen by around 10%, increase the strength and performance of road, avoid use of anti stripping agent, avoid disposal of plastic waste by incineration and land filling and ultimately develop a technology, which is eco-friendly. Increased traffic conditions will and are reducing the life span of roads [4].

Modified bitumen is expected to give higher life of surfacing depending upon degree of modification and type of additives and modification process used. Modification process is usually established by mainly one of two common ways; the first one is called the wet process where additive particles are mixed with asphalt at elevated temperature prior to mixing with the hot aggregates. The second type is called dry process, where additive particles replace a small portion of the mineral aggregate in the asphalt mix before the addition of the asphalt [2].This study was used wet process for additive particles to the virgin bitumen 60/70 penetration grade.

Al-ani, T. M. (2009) Study the effect of rubber silicon on the performance of asphalt mixture for different percent of added (1%, 2% 3% and 5%) by weight of binder. For this purpose the performance changes were evaluated by Marshall Tests and diametric tensile creep test. The study showed that the Rubber-Silicone has more effects on performance of asphalt mixture by increasing the Marshal stability, air voids, and reducing the flow and bulk density compared with the original mix. [4]. Rubber manufacturing can be Vulcanized rubber or Synthetic rubber. Vulcanization is a must process that generally applied to rubber or elastomeric materials to achieve rubber compounding by reaction with sulphur and accelerators at higher temperature. Synthetic rubber, which is made by the polymerization of a variety of petroleum-based precursors [6]. Synthetic rubber is basically a polymer or an artificial polymer [1]. It has the property of undergoing elastic stretch ability or deformation under stress, but can also return to its previous size without permanent deformation. Examples of synthetic rubber produced are including silicone rubber, butyl rubber, nitrile rubber, chloroprene rubber, foam rubber and the most usually operated is styrene butadiene rubber (SBR) [6].

There are many modification processes and additives that are currently used in bitumen modifications, such as styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) and crumb rubber modifier (CRM). The use of commercial polymers, such as SBS and SBR in road and pavement construction will increase the construction cost as they are highly expensive materials [7].

In this study, the bitumen content amount has been gradually decreased in the mixture by substituting it with 4% rubber-silicon and 8% (PET) by weight of the bitumen content. In order to see the gradual effect of the rubber-silicon and (PET), the changes are made in small percentage intervals of bitumen content. The bitumen content utilized in this study are 4%, 4.5%, 5%, 5.5%, 6%, and 6.5% by weight of the total mix which is weight of the samples (1200 gm).In this paper, the laboratory study on the hot mix asphalt is carried out by using Marshall Method of mix design to find the Optimal Asphalt Content (OAC). Marshall Properties such as Marshall Stability, flow value, bulk density, air voids, voids in mineral aggregates and voids filled with bitumen of three hot mix asphalt (conventional, modified by rubber-silicon and modified by polyethylene) are compared and conclusions are made on the basis of these results.

2. Materials and Methods

This section provides detailed information on the materials used and their properties. It also highlights the laboratory procedures for the tests performed. The main aim of the study is to provide more insight of the contribution the percentage of different modification of bituminous binder in Libyan conventional hot mix asphalt (HMA) towards enhancement the mixture properties. Based on this aim, the objectives have been achieved by conducting laboratory investigation. Laboratory investigation has including material characteristics, mix design method and experimental program. All data presented in this study had been conducted in the Road laboratory of Civil Engineering Department in Sebha University**.**

2.1. Aggregates

Crushed limestone aggregates collected from the nearby quarry (Abushkaka Mountain) were used to prepare bituminous concrete mix. The aggregates satisfied the necessary requirements for bituminous concrete mix and having good quality is used. The physical properties such as strength, toughness, hardness, shape and specific gravity of aggregates were tested as shown in table 1.

Table 1: The properties of aggregate.

Properties	Standards	Test Value
Soundness (%)	AASHTO T-104	13.96
Crushing (%)	AASHTO T- 96	9.96
Absorption (%)	AASHTO T-84	1.30
Bulk Specific Gravity (g/cm3)	AASHTO T-84	2. 65
Apparent Specific Gravity (g/cm3)	AASHTO T-84	2.75
Flakiness index (%)	BS – 812	14.66
Elongation Index (%)	BS – 812	13.93

2.2. Filler

One type of filler is used in this work which was Limestone dust that passing 0.075mm sieve is used. The quantity of mineral filler used is 2%.

2.3. Bitumen

One binder of asphalt cement was tested, from Azzawiya Refinery with a grade of (60-70) penetration. The physical properties (according to ASTM and AASHTO Specification) of this type are illustrated in Table (1). The binder contents utilized in this study are 4%, 4.5%, 5%, 5.5%, 6%, and 6.5% by weight of the total mix.

Table 1: The properties of asphalt.

Property	Conditions	Test	Asphalt Used
Specific Gravity	Pycnometer,25°C	ASTM D-70	1.028
Penetration,0.1 mm	25 °C , 100g, 5 Sec	AASHTO T-49	67
Flash Point, °C	Open Cup	AASHTO T-78	278
Ductility, cm	25 °C, 50 mm/min	AASHTO T-51	>100
Softening Point, °C	Ring and Ball	AASHTO T-53	56

2.4. Polyethylene-Therephthalate (PET)

PET is a semi-crystalline polymer has high tensile strength, high chemical resistance, and melting point of 260±10 °C. The waste bottles used in the study was PET and it was collected from the local waste plastic. The specific gravity of the plastic is found out to be 0.905. The HMA modified by PET was prepared with 8 % PET by weight of the asphalt content and the varying percentages of asphalt content 4%, 4.5%, 5%, 5.5%, 6%, and 6.5% by weight of the total mix.

2.5. Rubber-Silicone

Silicone rubber's special features such as "organosiloxanes polymer" has been originated from its unique molecular structure that they carry both inorganic and organic properties unlike other organic rubbers. In other words, due to the Si–O bond of silicone rubber and its inorganic properties, silicone rubber was superior to ordinary organic rubbers in terms of heat resistance, chemical stability, electrical insulating, abrasion resistance, weatherability and ozone resistance. With these unique characteristics, silicone rubber has been widely used to replace petrochemical products in various industries [7]. Rubber-Silicone was used with asphalt binder; it is available in the local market for sealants or glue stick. 4% Rubber-Silicon was added by weight to binder at different asphalt binder percent (4%, 4.5%, 5%, 5.5%, 6%, and 6.5%). Rubber-Silicone was added to binder at a temperature (150) °C with a stirrer for (20) minute.

3. Results and Discussion

3.1 Marshall Stability

The results obtained for various binder content are shown in Table 3 and illustrated in Figures 1.

Table 3: Stability analyser test results.

asphalt content %	*conventional*	**PET**	*Rubber-Silicone*
4	11.51	13.06	11.29
4.5	13.66	17.04	14.82
5	15.7	18.52	15.46
5.5	17.22	16.40	19.03
6	14.48	16.08	16.40
6.5	11.43	12.58	12.25

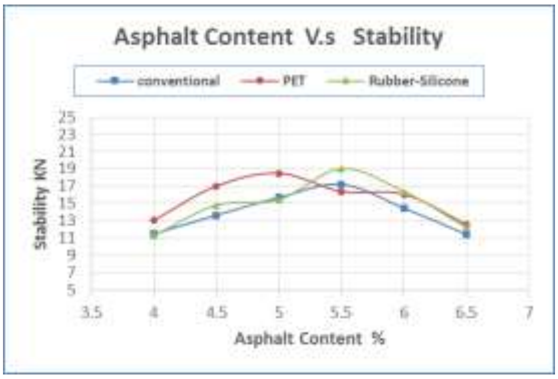

Fig. 1: Stability of three different mixtures

The Marshall Stability refers to the maximum load resistance escalated during the test procedure at 60∘C at a loading rate of 50.8 mm/min, before the compacted specimen failure. The Marshall stability is defined "as a measurement of the susceptibility of a bituminous mixture to deformation ensuring from frequent and heavy traffic load."
Table 1 illustrates the results of this test for unmodified samples and those modified with PET and Rubber-Silicone. Figures 1 shown the Marshall Stability value versus bitumen content for different HMA. The diagrams show the stability values for the differing binder content varying in tandem with the PET content. Once PET is added the stability value elevated until the maximum level, which was approximately 4.9 % of the used Bitumen, but then it started to decrease. In contrast to HMA modified with PET the HMA with Rubber-Silicone shown variation in the low bitumen content but the Stability value increase to peak at 5.6 % of the used Bitumen. In comparison to the unmodified mix (mix with 0% additive), the values of Marshall Stability were generally lowest value. Nevertheless, further injection of bitumen into the mixture led to a decrease in the value of stability because application of excessive bitumen decreases the coarse aggregate contact point within the mixture.

3.2 Marshall Flow

Flow can be understood to mean a measurement of the permanent strain which takes place in a

Marshall test at failure. It had indicated that the flow parameter as obtained from the Marshall test is rather unfortunate as a higher flow value does not necessary imply a higher tendency to flow or deform under load [23]. The results obtained for various unmodified samples and those modified with PET and Rubber-Silicone are shown in Table 4 and illustrated in Figures 2.

Figure 2 illustrates the Marshall Flow value versus binder content for each HMA. The results showed that the flow value increases with an increase in the bitumen content in the mixture; that is, the HMA flow value tends to increase with a higher binder content. This is due to the percentage of additional bitumen which allows the aggregates to float within the mix resulting in increased flow. In the case of the relationship between the Marshall Flow and HMA with Rubber-Silicone constituent, the flow value is higher in comparison with the HMA modified by PET and conventional HMA. As shown in Figure, the presence of PET in the mixture increases its flow value less gradually than HMA with Rubber-Silicone. This is due to the flexibility of Rubber-Silicone, which leads to a more flexible mixture.

Table 4: Flow analyser test results.

asphalt content %	***conventional***	**PET**	***Rubber-Silicone***
4	1.98	2.53	2.10
4.5	3.08	3.05	2.99
5	3.16	4.30	4.05
5.5	4.69	4.97	5.71
6	5.41	6.53	5.91
6.5	6.33	6.76	7.19

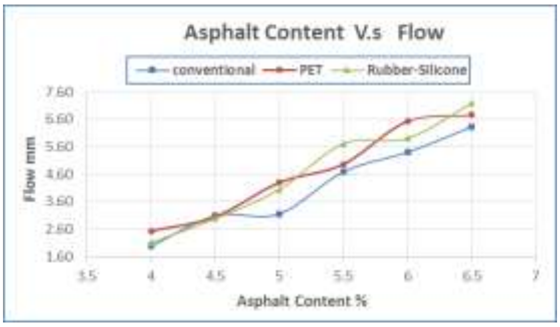

Fig. 2: Flow of three different mixtures

3.3 Bulk Density of mix (Gmb)

The results obtained indicated that binder content influences the compaction characteristics of the HMA mixtures, thus having a significant effect on the mix density. Table 5 and Figures 3 showed that, for any specific binder content, the density of the compacted mix is progressively increased, as the bitumen content of the mix increases.

Table 5: Density analyser test results.

asphalt content %	***conventional***	**PET**	***Rubber-Silicone***
4	2.41	2.33	2.36
4.5	2.42	2.42	2.45
5	2.44	2.45	2.48
5.5	2.46	2.46	2.47
6	2.44	2.45	2.47
6.5	2.44	2.45	2.45

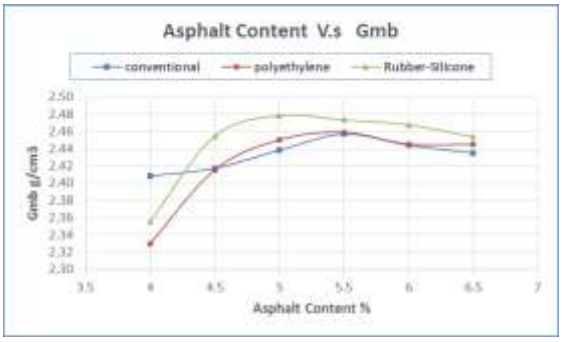

Fig. 3: Density of three different mixtures

This is due to the bitumen filling in the void space of the aggregate particles. The main reason for this is because of filling of the void space of the aggregate particles with bitumen. However, after filling the void space, the excessive percentage of the bitumen could lead to a significant increase in the density of the mixture. An explanation for the varying densities of the mixtures is because of the viscosity effect on the compatibility of the mixtures. The increase in viscosity could be a result of the amount of asphaltenes in the bitumen which improves the viscous flow of the modified bitumen sample during the interaction process.

3.4 Voids in the Mix (VIM)

The durability of bituminous pavement is a function of the voids of the mix (VIM) or porosity. The mix should contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. The compacted mix should not have very high air voids, which accelerates the aging process. In general, the lower the porosity, the less permeable the mixture and vice versa. Too much voids in the mix (high porosity) will provide passageways through the mix for the entrance of damaging air and water. Too low porosity could lead to flushing where the excess bitumen squeezes (bleeding) out of the mix to the surface. The effect of the additive content for different binder contents on the porosity of the virgin mixture shown in Table 5 and Figures 4.

Table 6: Voids in the Mix analyser test results.

asphalt content %	*conventional*	PET	*Rubber-Silicone*
4	6.32	9.38	8.38
4.5	5.27	5.35	3.82
5	3.73	4.03	2.17
5.5	2.34	2.27	1.70
6	2.27	2.23	1.33
6.5	1.85	1.56	1.10

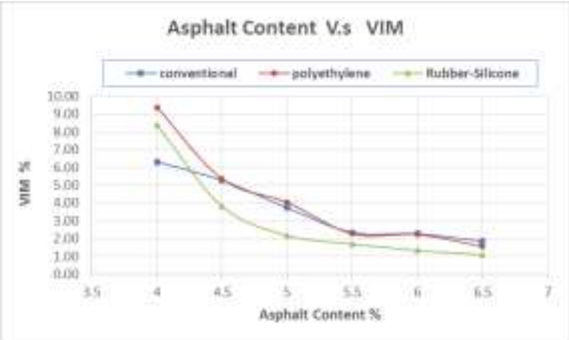

Fig. 4: Voids in the Mix of three different mixtures

Figure (4) shows the effect of rubber-silicone on the percentage of air voids in mixture. Air voids increase with increasing rubber-silicone binder content because of the decrease in the bulk density of mixture with increasing rubber-silicone. Figures (4) show that, for any binder content used, the increase in PET content in the mixture is followed by an increase in the VIM, which is due to the contact point between the aggregates which is lower when the PET is content increased. The high amount of PET particle absorbs the binder which is required to encapsulate the aggregate and subsequently fill the voids between aggregates. However, the results from Figure (4) concerning on the influence of bitumen show that any increase in the bitumen content of the mix leads to a decrease in the VIM value, which occurs due to the excessive bitumen filling up the air pocket between aggregates. It is therefore very important to produce a mix low enough in void to be impermeable and hence durable, but with sufficient voids to prevent bitumen deformation.

3.5 Optimum asphalt content (OAC)

The optimum asphalt content (OAC) was calculated by taking the average of the three values given below and as illustrates in Figure (5).

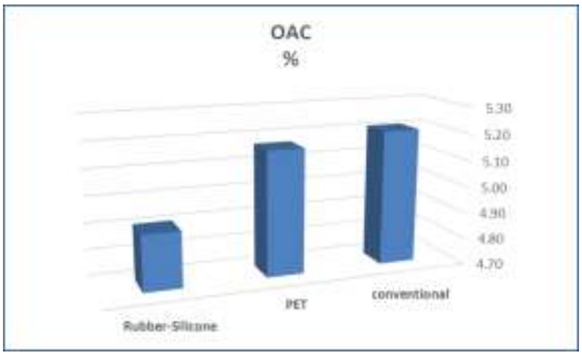

Fig. 5: optimum asphalt content (OAC) of three different mixtures

- The bitumen content corresponding to the maximum stability.
- The bitumen content corresponding to the maximum unit weight.
- The bitumen content corresponding to the median of the designed limits of percent air voids (VIM) in the total mix (4%).

4. Conclusion and Recommendation for Future Studies

Based on the study conducted, the following conclusions may be derived.

i. Stability is improved by adding modifier binders to the hot mix asphalt as better adhesion is developed. In comparison to the control mix (mix with 0% additive), the values of Marshall Stability for HMA modified with rubber-silicone were generally higher.
ii. Regardless of the amount of the incorporated additive, adding PET and Rubber-Silicone to the mixture increases the VIM of the mixture while decreasing its density.
iii. The least optimum bitumen content was found to be 4.91 % by weight of bitumen for hot mix asphalt modified by Rubber-Silicone.
iv. The volumetric and Marshall properties of hot mix asphalt modified by PET and Rubber-Silicone mixture show acceptable trends and could satisfy the standard requirements and Libyan specification.
v. Use of different types of aggregate, aggregate gradation, different mixing methods, different compaction methods and various percentage of additive is recommended for further studies.

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