**Civil Engineering Research Magazine**
**CERM**
**ISSN 1110-0990**
**Vol., 46 2025.**

# Laboratory Investigation of using a novel compound of RAP and polyethylene polymer into asphalt concrete

Ahmed Boraie [a], Mostafa Rabah [b], Moustafa Abdelsalam, [c] Ahmed Gamal [d]

[a] Civil Engineering Department, Al-Safwa High Institute of Engineering, Egypt
, E-mail: ahmedboraie_55@yahoo.com
[b] Civil Engineering Department, Benha Faculty of Engineering, Benha University, Egypt
, E-mail: mostafa_rabah@yahoo.com
[c] Civil Engineering Department, Benha Faculty of Engineering, Benha University, Egypt
, E-mail: eng_mostafaabdelsalam@bhit.bu.edu.eg
[d] Civil Engineering Department, Benha Faculty of Engineering, Benha University, Egypt
, E-mail: ahmed.morsy@bhit.bu.edu.eg

**الملخص :**استخدام الركام المعاد تدويره (RAP) في الخلطات الإسفلتية الساخنة أمرًا لا غنى عنه في معظم دول العالم. نظرًا لمحدودية المناطق المتوفرة في مدافن النفايات والمطلوبة للتخلص من RAP وكمية النقصان في الركام الطبيعي عالي الجودة،لذلك أصبح استخدام RAP في خلطات الخرسانة الإسفلتية الجديدة مهمًا جدًا في جميع أنحاء العالم. في هذه الدراسة تم التركيز على إعادة استخدام نسب الركام المعاد تدويره في تكوين الخلطات الإسفلتية الجديدة كعملية إعادة تدوير ودراسة تأثير إضافات البوليمر علي مواد الخلطة الإسفلتية الساخنة. لتحقيق أهداف الدراسة تم إجراء دراسات معملية على الخلطة الإسفلتية بدون إضافات،خلطات اسفلتية تحتوي علي نسب 25%، 50%، 75%، 100% من الركام المعاد تدويره بدلا من ورن الركام الخام. وكذلك تم استخدام 1% و2% و3% و4% من البولي إيثيلين بدلاً من وزن 50% من الركام الخشن المعاد تدويره. تتبع هذه الدراسة تقنية مبتكرة لمقارنة أداء الخلطات الاسفلتية في طريقة الخلط الجافة. وفي نهاية الدراسة ولتقييم هذه الخلطات تم إجراء بعض الاختبارات مثل اختبار فقدان الثبات، واختبارمسارات العجلات، وقوة الشد غير المباشرة. ومن خلال تحليل النتائج المعملية لوحظ أن استخدام الخلطات التي تحتوي علي ركام معاد تدويره والبولي إيثيلين يحسن بشكل كبير خواص الخلطات الإسفلتية ويعطي تقريبا نفس نتائج الخلطة التقليدية. وأخيراً أوصت النتائج المعملية باستخدام الخلطات التي تحتوي على 50 % ركام معاد تدويره بدلاً من وزن الركام الخشن الخام في الخلطة الإسفلتية الساخنة (HMA) والخلطات التي تحتوي علي 2% بولي إيثيلين من وزن 50% من الركام الخشن المعاد تدويره في الخلطة الإسفلتية. وحققت هذه الخلطات أفضل خواص للخلطة الإسفلتية وتضمنت أداء أفضل في قطاع الرصف.

**Abstract:** Using of reclaimed asphalt pavement (RAP) in hot asphalt mixes has been become indispensable in most of the world nations. Due to limited areas available in landfills which are required to eliminate the RAP and the amount of high quality natural aggregate decreases, the use of RAP in new asphalt concrete mixes has become very important all over the world. In this study, the focus was on reusing proportions of recycled aggregates in the formation of new asphalt mixtures as a recycling process and investigates the effect of polymer additives on hot mix asphalt containing (RAP) materials. In order to achieve the objectives of the study, Laboratory studies were carried out on asphalt mixture without additives , mixtures produced by different percentages RAP 25%, 50 %, 75% and 100% instead of the weight of raw aggregate and mixes contains different percentages 1%, 2%,3% and 4 % of polyethylene instead of the weight of 50% reclaimed coarse aggregate was used. This study follows an innovative technique to compare the performance of HMA prepared in dry mixing processes. At the end of the study, to evaluate these mixtures, some tests were performed such as loss of stability test, wheel tracking test and indirect tensile strength. By analyzing laboratory results, It was noted that the use of reclaimed asphalt pavement and polyethylene significantly improve the properties of asphalt mixtures and gave nearly the same strength parameters as virgin bituminous mix. Finally, laboratory results recommended the use of mixtures containing 50% RAP instead of the weight of raw coarse aggregate in hot mix asphalt (HMA) and mixes containing of 2% polyethylene instead of the weight of 50% reclaimed coarse aggregate in asphalt mixture. These mixes achieved the best properties of the asphalt mixture and included better performance in the paving sector.

**Keywords:** Reclaimed Asphalt Pavement (RAP), polyethylene, Asphalt Mixes, Loss of stability, wheel tracking test and indirect tensile strength**.**

## 1.Introduction

RAP is old asphalt pavement that is milled up or ripped off the roadway [1]. The use of reclaimed asphalt pavement has become a focus of attention.

Recycled asphalt pavement (RAP) combined with wax additives are processed into the asphalt mixture to meet the challenge of increasing the cost of raw materials and obtaining an environmentally friendly mixture. In the current years in Egypt, the cost of road maintenance is high compared to the cost of building new roads annually.

On the other hand, there is a continuous increase in the price of asphalt binder due to the increase in the cost of crude oil, so RAP materials must be used in the production of HMA mixtures. Because its use will help to maintain raw aggregate, binder, reduce pavement thickness and reduce the cost of asphalt mix.

Nowadays, Recycled aggregates are used in road layers. Where the recycled aggregate was used in paving the shoulders of rural and urban roads by cold or hot recycling in place. This method ensures that a very small amount of additives is added to the asphalt [1].

Annually, up to 100 million tons of hot asphalt is produced, according to the Federal Highway Administration (FHWA) [2]. One of the most important reasons that led to the use of recycled aggregates is to get rid of the need to use aggregates and asphalt in the existing sidewalks. [3].

The materials are classified after the removal of asphalt pavements for reused and maintenance. Reclaimed asphalt pavement contains of high-quality, well-graded aggregates coated with asphalt cement with high moisture content [2].

Recycled aggregates have excellent properties that make them a substitute for virgin resources and thus have the ability to reduce the use of virgin aggregates in mixtures. As a result, its properties make it an environmentally friendly and cost effective alternative to virgin aggregates. Another advantage of using RAP is that it helps reduce the amount of expensive new asphalt binders used in asphalt paving mixes. [4].

In addition to, in 2018, more than 100 million tons of RAPS was collected for reuse in the United States, thereby saving about 61.4 million cubic yards of landfill space. The use of reclaimed asphalt pavement has become attractive because of its effectiveness in terms of reducing costs and preserving the environment [5].

In another study conducted on the use of aggregates, it was found that its use in high proportions has an effect on reducing the shear strength [6]. In contrast to the use of virgin aggregates, the use of recycled aggregates reduces the bearing capacity of the materials. Therefore, its use in large quantities led to the deterioration of the CBR values. Therefore, it was recommended to mix recycled aggregates with virgin aggregates in a proportion not exceeding 50% [7].

## 2. Study Objective:

One of the objectives of this study is to reuse proportions of recycled aggregates in the formation of new asphalt mixtures as the recycling process and investigate the effect of polymer additives on hot mix asphalt containing (RAP) materials.

## 3. STUDY METHODOLOGY:

The objectives of the study are summarized as follows:

- Using Marshall Methodology with different percentages of bitumen content (3.5, 4, 4.5,5 and 5.5%) by weight of the mix to Identifying Optimum Bitumen Content (OBC).

- Study the behaviour of adding different percentages of reclaimed Asphalt pavement materials (25%, 50 %, 75% and 100 %) of the weight of raw aggregate and determine the optimum percent of (RAP) materials to be added in hot asphalt mixtures.

- Evaluate the specimens of asphalt mixture containing percentage of polyethylene( 1,2,3,4) % instead of the weight of 50% reclaimed coarse aggregate with percentage of bitumen content 3.56% to obtain the optimum replacement ratio of polyethylene.

## 4. Materials and Experimental Methods

In this study, raw material which selected were Obtained from known sources from Egypt. To evaluate these materials such as Coarse and fine natural aggregates, mineral filler, polyethylene materials and Asphalt binder materials Laboratory tests were performed. To determine the optimum bitumen content Marshall Methodology was used, the best percentages of RAP and evaluate of using percentages of polyethylene. Some tests will be done to evaluate performance of asphalt mixtures. These mixes were subjected to laboratory tests which include loss of stability, wheel tracking and indirect tensile test.

### 4.1. Materials

### 4.1.1 Asphalt Cement

Asphalt with 60/70 penetration was obtained from Suez, Egypt is chosen in all experiments in this research]. The fundamental properties of the selected Asphalt are illustrated in table 1, as per Egyptian specification.

Table 1. Characteristics of asphalt

| Index | Unite | Value | specification |
|---|---|---|---|
| **Penetration ,** | 0.1mm | 64 | **60-70** |
| **Softening point** | ºC | 52 | **45-55** |
| **Flash point** | ºC | +270 | **+250** |
| **Kinematic viscosity** | Cst | +345 | **+320** |
| **Ductility** | **Cm** | **130** | **≥ 95** |

### 4.1.2 Aggregates

Two sources of Dolomite coarse aggregates (Pin 2, Pin 1), used in the present study, were obtained from the “Ataka” quarry in Suez, Egypt. Various qualification tests were conducted to determine the engineering properties of the selected aggregates. The measured values of these tests are displayed in Table 2, according to Egyptian specifications. Siliceous sand that was obtained from “Elrehab” quarry, Cairo, was used as the fine aggregate and has a density of 2.68 g/cm3. Furthermore, limestone powder with a density of 2.75 g/cm3 was selected as the mineral filler. The gradation of the coarse and fine aggregates used in this research is investigated in Table 3, according to AASHTO T27.

Table 2. Properties of coarse aggregates

| Index | Values | | Standard |
|---|---|---|---|
| | **pin 1** | **pin 2** | |
| **Los Angeles abrasion value** | 26.5% | 26.2% | ≤ 40% |
| **Water absorption value** | 1.3% | 1.2% | ≤ 5% |
| **Apparent Specific gravity** | 2.788 | 2.755 | ------------- |
| **Stripping value** | > 95% | > 95% | > 95% |

Table 3. Gradation of aggregates as a percent of those passing through sieve.

| **Sieve Size, Inch** / **Material** | **1** | **3/4** | **1/2** | **3/8** | **No. 4** | **No. 8** | **No. 16** | **No. 30** | **No. 50** | **No. 100** | **No. 200** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coarse aggregate (Pin 2) | 100 | 84 | 15 | 5 | 2 | - | | - | - | - | - |
| Coarse aggregate (Pin 1) | 100 | 100 | 91 | 54 | 2 | - | | - | - | - | - |
| Fine aggregate | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 65 | 30 | 6 | 3.5 |
| Mineral filler | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 95 |

### 4.1.3 Recycling Aggregate

Recycled aggregate is collected from the Development of the Cairo-Ismailia Desert Road. Table 4 illustrates the gradation of reclaimed aggregate.

Table 4. Gradation of RAP

| **Sieve size** | **RAP (passing percent)** |
|---|---|
| 1 inch | 100 % |
| ¾ inch | 79 % |
| ½ inch | 0 % |
| 3/8 inch | 0 % |

### 4.1.4 Waste Plastic Resin

Waste plastic resin is a synthetic plastic material with a Linear Low-Density Polyethylene (LLDPE), which is used in this study as additives into the asphalt mixes. The chemical properties of waste plastic resin are represented in table 5 and the morphology of waste plastic resin is illustrated in figure 1.the plastic resign material from a factory on the Cairo-Ismailia Desert Road.

Table 5. Characteristics Chemical of waste plastic resin polyethylene

(Provided by the manufacturer)

| **Index** | values | Specification |
|---|---|---|
| Bulk Density | 0.926 gm. /cm3 | ExxonMobil method |
| solubility index (190ºc/2.1kg) | 50 g /10 min | AST MD1238 |
| Maximum melting temperature | 121ºc | ExxonMobil method |
| Vicat softening temperature | 91ºc | ISO 306 |
| Tensile stress value | 11 MPs | Iso527-2/1A/50 |
| Tensile strain value | 20% | Iso527-2/1A/50 |
| Tensile strain at break | >100% | Iso527-2/1A/50 |
| Value For Flexural | 290Mpa | ISO 178 |
| Value For Environmental stress and crack resistance 10 % Igepal | 7 hr. | ASTMD 1693 |

Figure (1): Linear Low density polyethylene Resin

### *4.1.5 Mix Gradation*

The gradation values of the mix design (3C) were selected in all experimental plans. The mix design selected is shown within the limits in table 6 and figure 2.

Table 6. The Design Gradation of the asphalt mix (3C)

| **Sieve Size** | **1"** | **3/4"** | **1/2"** | **3/8"** | **No.4** | **No.8** | **No.16** | **No.30** | **No.50** | **No.100** | **No.200** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Selected Mix Design** | **100** | **94.40** | **67.01** | **50.19** | **30.42** | **29** | **28.73** | **19.55** | **10.10** | **3.58** | **2.80** |
| **Specification limits (3C)** | **100** | **75-100** | **-----** | **45-70** | **30-50** | **20-35** | **----** | **5-20** | **3-12** | **2-8** | **0-4** |

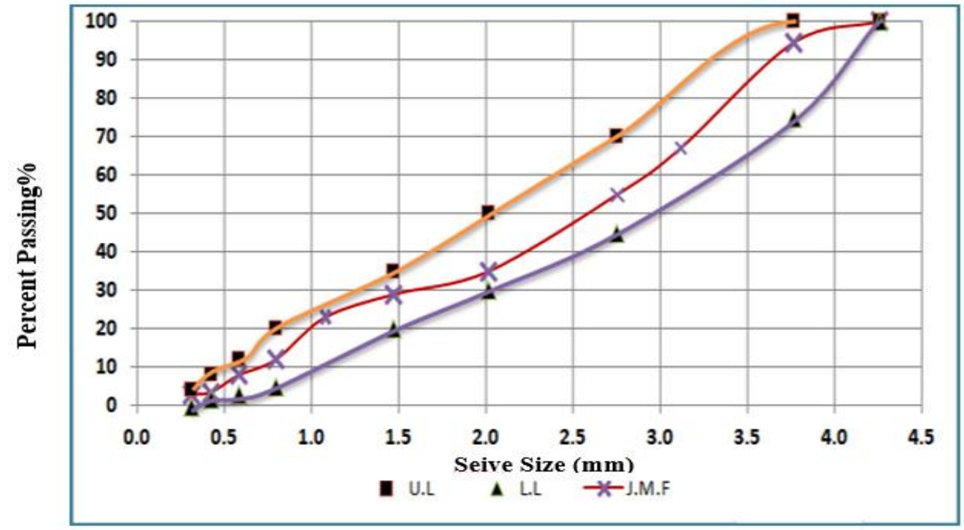


Figure 2: Gradation of Asphalt mix (3-C) design used in the experiments

## 4.2 Experimental Method:

### 4.2.1 Specimen Preparation

Eight types of asphalt concrete mixes were fabricated in laboratory and used to assess the performance with regard to loss of stability and moisture damage resistance. The additives amount, type, and optimum bitumen content (O.B.C) are mentioned in Table 7.

Table (7): Classification of mixtures used in the study

| Mix ID | additives | additives amount | O.B.C |
|---|---|---|---|
| M0 | Non | 0 | 4.40% |
| M1 | RAP | 25% instead of aggregate weight | 3.60% |
| M2 | RAP | 50% instead of aggregate weight | 3.56% |
| M3 | RAP | 75% instead of aggregate weight | 3.63% |
| M4 | RAP | 100% instead of aggregate weight | 3.64% |
| M5 | RAP + polyethylene | 1% instead of 50% RAP | 3.56% |
| M6 | RAP + polyethylene | 2% instead of 50% RAP | 3.56% |
| M7 | RAP + polyethylene | 3% instead of 50% RAP | 3.56% |
| M8 | RAP + polyethylene | 4% instead of 50% RAP | 3.56% |

### 4.2.3 Asphalt Mixture Performance Tests

#### 4.2.3.1 Loss of *stability test*

Loss of stability test is used as an indicator of the water resistance of Marshall Samples and is a simplified version of AASHTO T-165. In this test, two groups of asphalt mixes samples with dimensions (101.6 diameter X 63.5 mm high) were manufactured in laboratory based on O.B.C. After that, one group of Samples was immersed in water bath at 60°C for 30 min while the other group was submerged in water at 60°C for a period of (0, 1 day, 2 days, and 3 days) .finally, the samples were tested on a Marshall device to determine the loss of stability from one to three days .

#### 4.2.3.2 Wheel tracking test

The wheel tracking test (WLTT) was conducted to measure the rutting in the mixes and this test was developed by British Road Research [8]. WLTT consists of a rubber wheel with a weight 53.5 kg. The track depth at the mid-point of its length is recorded at regular intervals up to 45minutes by a spring dial gauge. Samples were prepared in this test at 60°C in a water bath according to (AASHTO T-340) [9]. HMA slap dimensions (length × width × thickness) of 440×350×50 mm It has been compacted and prepared in the optimum bitumen content according to General Authority for Roads, and Land Transport, Egypt [10].

#### 4.2.3.3 Indirect Tensile Strength

In accordance with ASTM D6931, an indirect tensile strength test was performed. In this test, the cylindrical samples were subjected to pressure loads operating parallel to the diagonal vertical plane using the Marshall loading device, and this method was illustrated in figure (3). As a result of this loading, a uniform tensile stress is produced, which works perpendicular to the applied load plane, and therefore the sample fails by splitting with the loaded plane. From the following equation the indirect tensile force was determined:

$$\boxed{ITS = \frac{2000 \times P}{\pi \times H \times D}}$$

Where: ITS is the value of indirect tensile strength (kPa); P the Maximum failure load (N); h is the thickness for the sample (mm); and D is diameter for sample (mm). The level of damage caused by moisture depends on the design of the pavement, environmental factors, and the quality of the materials used in the asphalt mixture. Therefore, the wettability of the compressed samples was evaluated by the tensile strength ratio (TSR) using the following equation.

$$\boxed{TSR = \frac{ITS_{cond}}{ITS_{uncond}}}$$

Where: ITS Cond is it is considered the average value of the indirect tensile strength while ITS uncond is the average value of the indirect tensile strength in the dry state (unconditioned) specimen.


Figure (3) machine for indirect tensile test

## 5. RESULTS AND DISCUSSION

### 5.1 Conventional Mix Results:

The mechanical properties of the control mix, which contained ratios of natural aggregates with asphalt ratios from 3.5 to 5.5% with an increment of 0.50 to determine the optimum asphalt binder content, are shown in Table 8. According to the results, the study showed that the best content of bitumen is found to be equal to 4.4% of the weight of the total mix, which fulfills the specifications of the Egyptian code.

A summary of the results for all the mixtures,the conventional mixture, mixtures containing different percentages of RAP, and mixtures containing different percentages of polyethylene is presented in Table 9.

Table 8. Marshall Results for control mix according to Egyptian specifications.

| Asphalt Content | Stability (Kg) | Flow (mm) | Bulk Density (gm/cm³) | AV (%) | VMA (%) |
|---|---|---|---|---|---|
| 3.5% | 1101 | 2.4 | 2.33 | 6.07 | 15.61 |
| 4% | 1517 | 2.6 | 2.34 | 4.24 | 15.15 |
| 4.5% | 1671 | 2.8 | 2.35 | 3.48 | 15.55 |
| 5% | 1751 | 3 | 2.34 | 3.33 | 16.50 |
| 5.5% | 1694 | 3.3 | 2.33 | 3.18 | 17.00 |
| Specification Limits | 900 minimum | 2–4 | ---- | 3–8 | 14 minimum |

Table 9. Summary of results for all Marshall mixes.

| Mix No. Property | M0 | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 |
|---|---|---|---|---|---|---|---|---|---|
| Density (gm./cm$^3$) | 2.35 | 2.34 | 2.33 | 2.32 | 2.30 | 2.25 | 2.23 | 2.19 | 2.18 |
| Stability (kg) | 1600 | 1370 | 1300 | 1255 | 1234 | 1674 | 1866 | 2200 | 2360 |
| Flow (mm) | 2.73 | 2.79 | 2.9 | 3.57 | 3.9 | 2.6 | 3.1 | 3.6 | 4.5 |
| AV% | 3.4 | 4.7 | 4.85 | 4.1 | 3.9 | 5.8 | 4.91 | 4.78 | 4.5 |
| VMA% | 15.6 | 15.2 | 15.25 | 14.32 | 14.21 | 15.11 | 15.16 | 15.17 | 15.57 |
| OBC | 4.4% | 3.60% | 3.56% | 3.63% | 3.64% | 3.56% | 3.56% | 3.56% | 3.56% |

## 5.2 Results for Asphalt mixes modified by different percentages RAP:

## Mechanical Properties

A summary of the results for the control mixture, mixes containing different percentages of RAP, and mixes containing different percentages of polyethylene is presented in Table 9.

Figure 4 and Table 9 show the OBC values for various amounts of RAP. The lowest value for bitumen content was at 50% RAP. As the RAP contents increased from 0% to 50%, the OBC decreased by about 19.1%. The increase in the amount of RAP led to an increase in the OBC due to the increase in the amount of bitumen, which was contained inside the RAP because of the increase in the RAP percent from 25% to 100%.

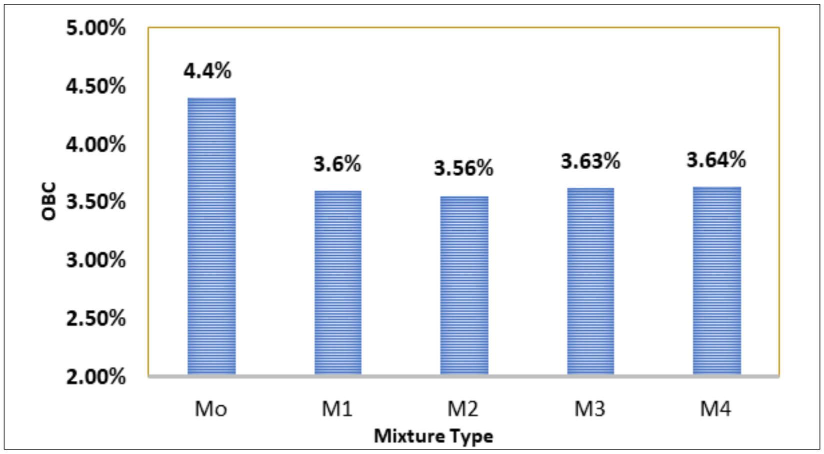


**Figure 4.** OBC of RAP asphalt mixes.

Figure 5 and Table 9 show the density of the control mix and mixtures modified with different percentages of RAP contents. Increasing the RAP content from 0% to 100% slightly decreases the bulk density. The decrease in the bulk density value could be attributed to an increase in bitumen percent, which was contained inside the RAP. Also, we replaced the same weight of raw aggregate with RAP, which consisted of aggregate and bitumen with a low specific gravity, and this was the reason behind the decreasing density. However, the decrease in the bulk density and the increase in the OBC from M1 to M4 were insignificant.

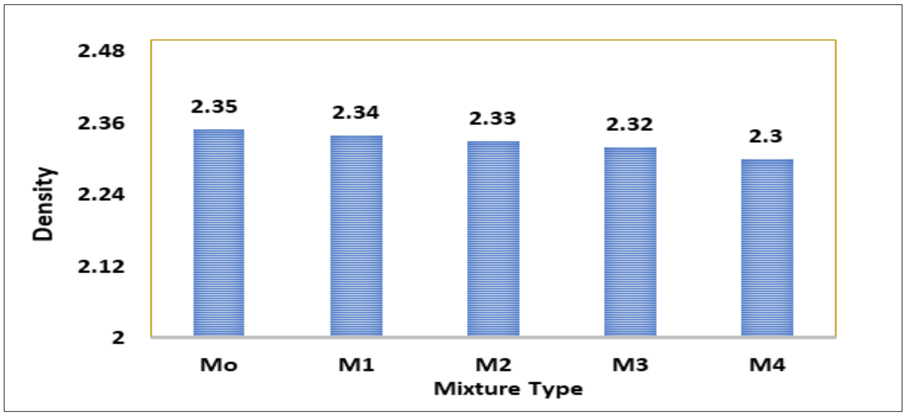


**Figure 5.** Bulk density of RAP asphalt mixes.

Figure 6 and Table 9 exhibit the Marshall Air voids of the control mix and the mixes modified with different percentages for RAP contents. The addition of RAP in an amount of 25% up to 100% increased the number of air voids compared with the number in the control mix. This was due to the constant particle size of the RAP, which was 79% less than three-quarters of an inch and had no percentage passing through a sieve with half-inch holes, as shown in Table 2. This replaced the 3D gradation for the normal mix, as shown in Table 3. Figure 6 also illustrates that the number of air voids increases with an increasing RAP percent from 0% to 50% and then decreases from 50% to 100%; this is due to the compound effect of increasing the RAP percent when it has a constant particle size, as discussed before, and increasing the bitumen percent contained inside the RAP. Increasing the RAP content from 0% to 50% increases the number of air voids by 42.65%. A decrease in the air void percent from 50% to 100% results from increasing the OBC in mix M3 (75% RAP instead of the weight of coarse aggregate) and M4 (100% RAP instead of the weight of coarse aggregate), as shown in Figure 6 and Table 9. All numbers of air voids for the mixtures with different percentages of RAP meet the limits of Egyptian standards.

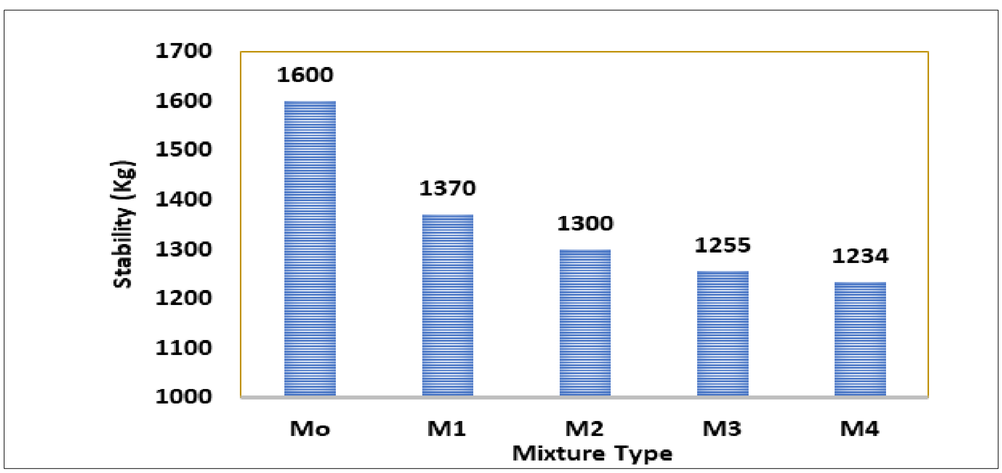


**Figure 6.** Air voids of RAP asphalt mixes.

Figure 7 and Table 9 illustrate that all the stability results satisfy the minimum specification limits of Egyptian specifications. Also, increasing the RAP proportions and, therefore, bitumen percent, which was contained

inside the RAP, decreased the stability of asphalt mixtures. The addition of RAP in percentages of 25%, 50%, 75%, and 100% decreased the results of stability by 14.38%, 18.75%, 21.56%, and 22.88%, respectively.
The stability values decrease with an increase in the RAP amount and this is due to the presence of reused aggregate in the RAP instead of virgin aggregate, which makes the mixture less stiff. But, with an increase in both the RAP content and polyethylene, the stiffness increased. Also, adding RAP only decreases the stiffness. This confirms the idea that using RAP alone is not enough as a recycled material.

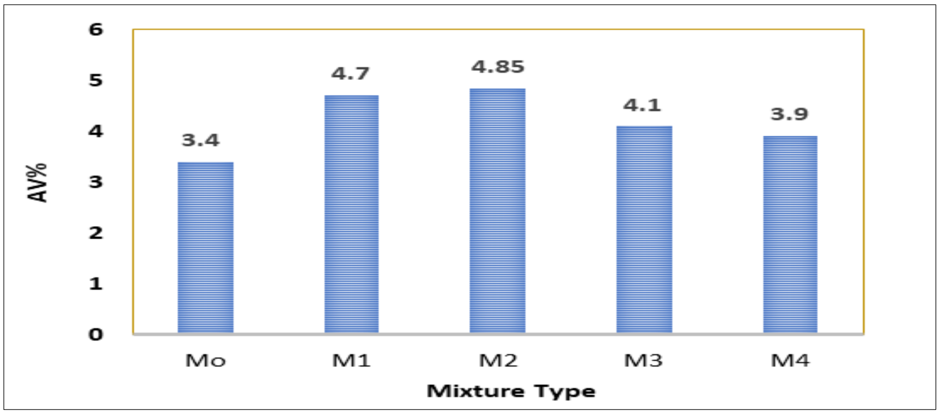


**Figure 7.** Stability of RAP asphalt mixes.

Figure 8 and Table 9 show the Marshall flow for the control and modified mixtures with different percentages of RAP contents. Increasing the percentage of RAP from 0% to 50% increased the value of flow from 2.73 mm to 2.9 mm, which is approximately near the middle of the limits of the specifications. Increasing the percentage of RAP from 0% to 100% increased the value of flow from 2.73 mm to 3.9 mm, which is approximately near the upper limit of the specifications. The increase in the flow value is attributed to the increase in the bitumen percent, which is contained inside the RAP.

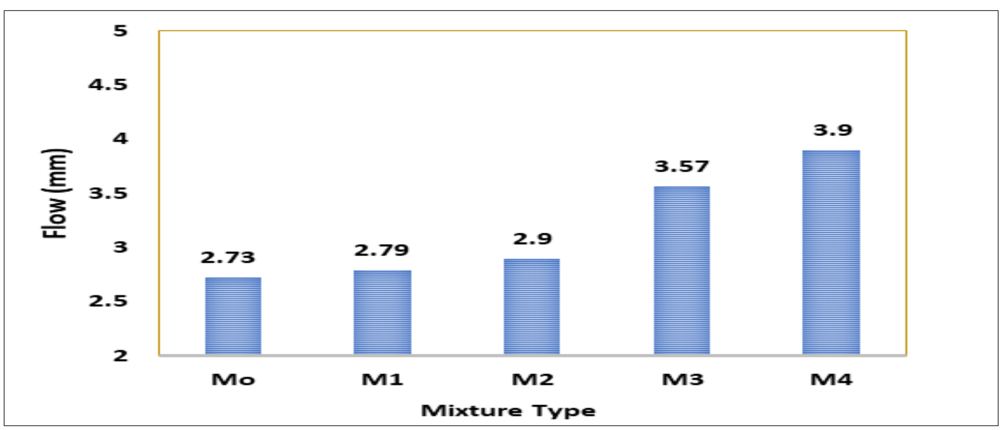


**Figure 8.** Flow of RAP asphalt mixes.

Figure 9 and Table 9 show the Marshall voids in the mineral aggregates (VMA) of the control mix and mixes modified with different percentages of RAP contents. The number of VMA decreased with an increasing RAP ratio. A lower number of VMA was recorded for mixture No. 4. All the mixtures lay within the specification range according to the Egyptian code.

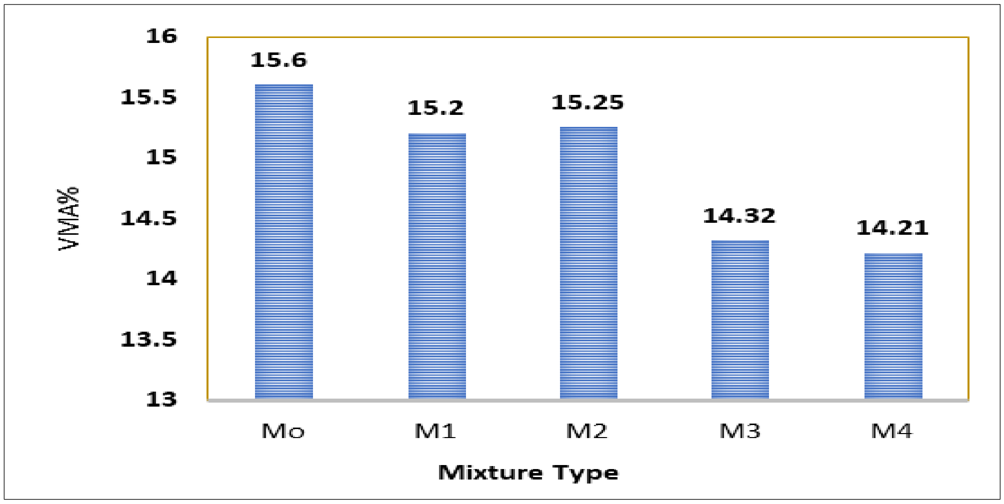


**Figure 9.** Voids in mineral aggregates of RAP asphalt mixes.

Analyzing the results for the asphalt mixtures modified with recycled aggregates, all the RAP percentages meet the limits of the Egyptian standards. Adding RAP to the mix in a 50% proportion can help save more natural aggregate, consume more RAP, and reduce the percentage of used bitumen required to manufacture asphalt concrete mixtures. This is one thing that will reduce the cost and environmental impact. A comparison between the properties of the asphalt mixes modified with 50% RAP (M2) and the conventional mix (M0) is illustrated in Table 10.

**Table 10.** Comparison between M0 and M2 characteristics.

| Property | M0 | M2 | Egyptian Specification Limits | Rate of Change |
|---|---|---|---|---|
| Optimum Bitumen Content, % | 4.4 | 3.56 | - | −19.09% |
| Stability, Kg | 1600 | 1300 | 900 minimum | −18.75% |
| Flow, mm | 2.73 | 2.9 | 2–4 | +6.22% |
| Density, gm./cm3 | 2.35 | 2.33 | - | −0.85% |
| Air Voids, % | 3.4 | 4.85 | 3–8 | +42.6% |
| Void in Mineral Aggregate, % | 15.6 | 15.25 | 14 minimum | −2.24% |

## 5.3 Results for Asphalt Mixes Modified with RAP and Polyethylene

Figure 10 and Table 9 show that increasing the polyethylene percentages by 1%, 2%, 3%, and 4% instead of adding 50% RAP decreased the bulk density values compared with the control mix by 4.26%, 5.11%, 6.81%, and 7.23%, respectively. The decrease in bulk density shows the effect of adding polyethylene.

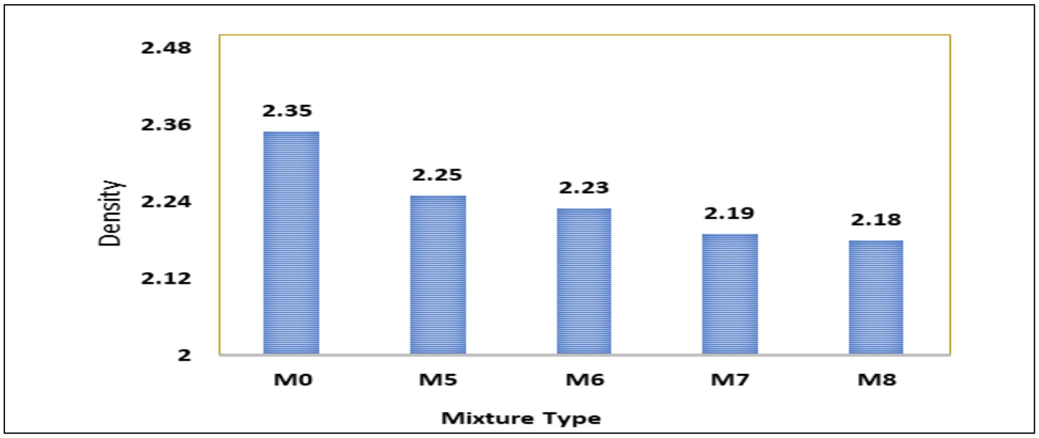


**Figure 10.** Bulk density of mixtures containing RAP and polyethylene.

Figure 11 and Table 9 show that increasing the polyethylene percentages by 1%, 2%, 3%, and 4% instead of adding 50% RAP increased the air void values compared with the control mix by 70.59%, 44.41%, 40.59%, and 32.35%, respectively. The air void values for all the mixes modified by polyethylene satisfy Egyptian standards. The increase in air voids in the RAP polyethylene mixes compared with the control mix could be attributed to replacing the RAP amount with virgin coarse aggregate. Adding polyethylene percentages from 1% to 4% instead of 50% RAP decreased the air void values by 22.41%. This is because of the remaining polyethylene which did not melt in the bitumen. The remaining polyethylene plays an important role in closing the mixture voids.

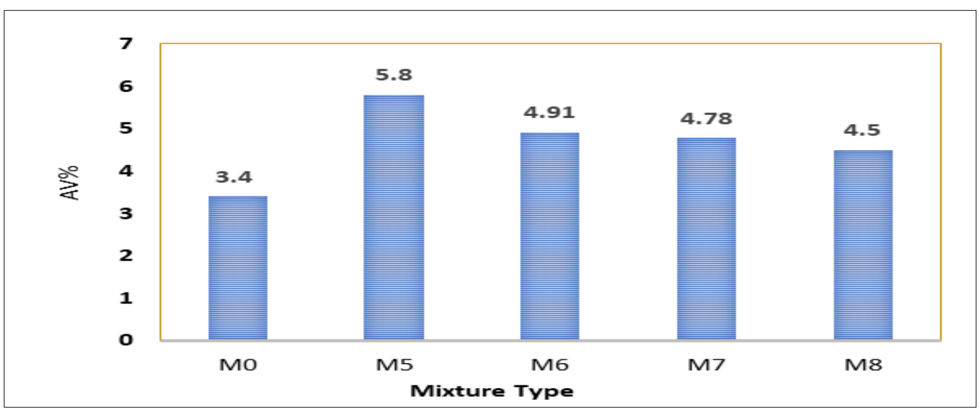


**Figure 11.** Air voids in mixtures containing RAP and polyethylene.

Figure 12 and Table 9 show that increasing the polyethylene percentages by 1%, 2%, 3%, and 4% instead of adding 50% RAP increased the stability values compared with the control mix by 4.63%, 16.63%, 37.5%, and 47.5%, respectively. The stability values for all the mixes modified by polyethylene satisfy Egyptian standards. The increase in stability shows the effect of adding polyethylene (as a part of the RAP), which is a kind of thermoplastic material. Part of the melted polyethylene reacted with bitumen due to the polyethylene having the highest mixing temperature combined with lowest the melting temperature. This reaction improves the mixture's stiffness.

The stability of control mix M0 is 1600 kg, while the stability of the mixes which contain RAP only ranges from 1370 kg to 1234 kg. Adding RAP percents ranging from 25% to 100% instead of the weight of coarse aggregate (Pin 2) and then adding 4% polyethylene instead of 50% RAP to the mix increased the stability to 2360 kg. This increase in stability is because of adding polyethylene (as a part of the RAP). A part of the polyethylene was melted in bitumen, and the remaining part of polyethylene, which was not dissolved, was used as an aggregate; both types of polyethylene (melted and not dissolved) help in increasing the Marshall stability.

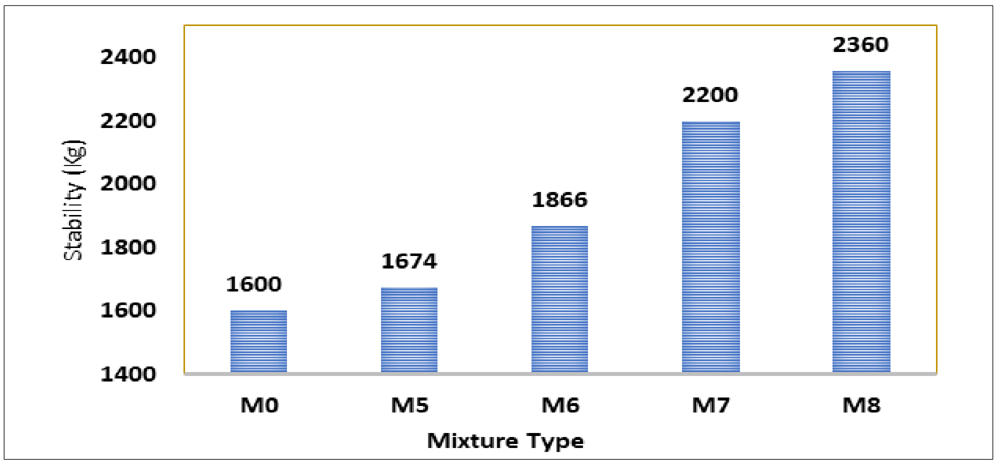


**Figure 12.** Stability of mixtures containing RAP and polyethylene.

Figure 13 and Table 9 show that increasing the polyethylene percentages by 1% instead of adding 50% RAP decreased the flow values compared with the control mix by 4.76%. Also, increasing the polyethylene percentage by 2%, 3%, and 4% instead of adding 50% RAP increased the flow value compared with the control mix by 13.55%, 31.87%, and 64.84%, respectively. The flow values for all the mixes modified by polyethylene satisfy Egyptian standards, except for the value of 4% polyethylene. The increase in flow causes an increase in the bitumen percent, which is contained inside the RAP, as well as the melting of some parts of the polyethylene.

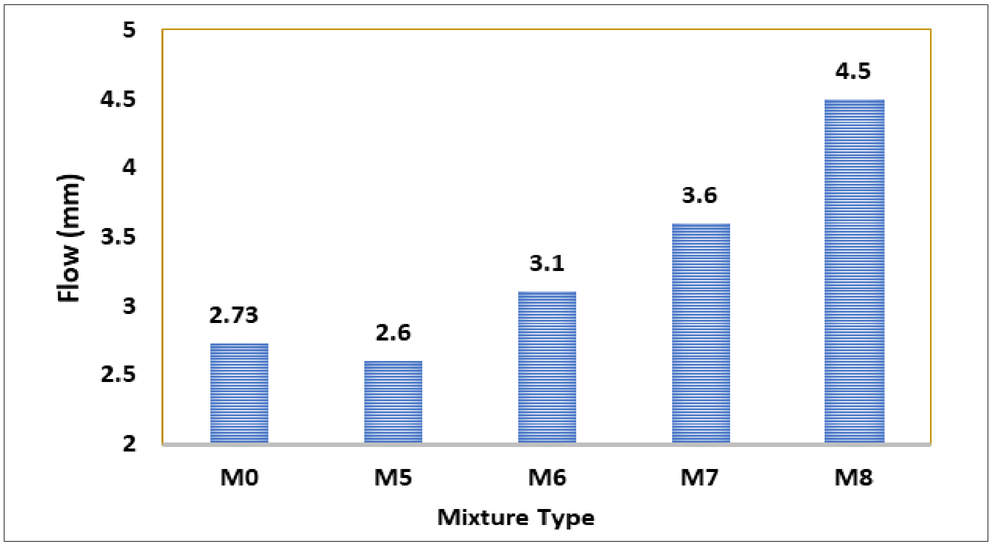


**Figure 13.** Flow of mixtures containing RAP and polyethylene.

Figure 14 and Table 9 show that increasing the polyethylene percentages by 1%, 2%, 3%, and 4% instead of adding 50% RAP decreased the number of voids in the mineral aggregate compared with the control mix by 3.14%, 2.82%, 2.76%, and 0.2%, respectively. The number of voids in the mineral aggregate for all the mixes modified by polyethylene satisfied the Egyptian standards.

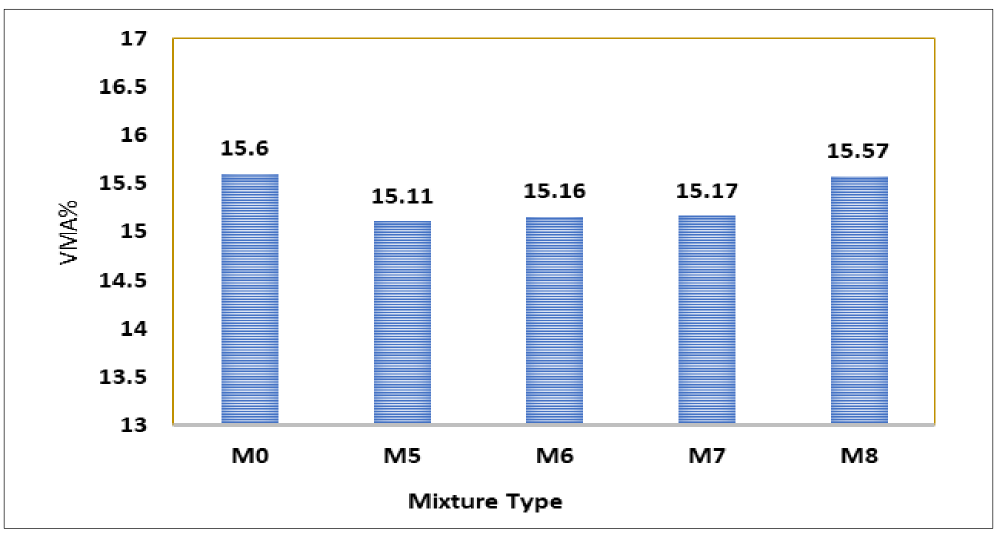


Figure 14. Voids in mineral aggregate of mixtures containing RAP and polyethylene.

Figures 10–14 display the ratios of 1%, 2%, and 3% of polyethylene instead of the weight of 50% RAP, which meet the limits of the Egyptian standard. A content of 2% polyethylene instead of 50% RAP was chosen, and the declared percent gives medium values for all the Marshall criteria between 1% and 3%, approximately. In addition, the greater amount of polyethylene may lead to many risks for the environmental profile. Table 11 shows a comparison between the properties of the asphalt mixtures modified with 2% polyethylene instead of 50% RAP (M6) and the control mix's properties (M0). The performance of the polyethylene-modified asphalt mixtures was proven to be better than that of the conventional mixtures.

**Table 11.** Comparison between M0 and M6 characteristics.

| Property | M0 | M6 | Egyptian Specification Limits | Rate of Change |
|---|---|---|---|---|
| Stability, kg | 1600 | 1866 | 900 minimum | +16.6% |
| Flow, mm | 2.73 | 3.1 | 2–4 | +13.55% |
| Air voids, % | 3.4 | 4.91 | 3–8 | +44.41% |
| VMA, % | 15.6 | 15.16 | 14 minimum | −2.82% |

## 5.4. Loss of Stability Results

The durability of the asphalt mixture over time at 60 °C for the mixtures M0, M2, and M6 is evaluated by the loss in stability test. Figure 15 illustrates that the stability loss for all the mixes increased with the increase in immersion days. The percentages presented in Figure 15 were calculated based on the results of stability for the same mixes shown in Table 9. All the results for all the mixtures satisfy the specifications limit (Max 25%) according to LTG 2015.

After the third day of immersion, the best result was 6.5%, which was obtained for M6. Lower results, 12% and 13%, were obtained for M0 and M2, respectively. The use of RAP alone increased the loss of stability, therefore weakening the durability of the asphalt mixture. On the other hand, adding polyethylene decreased the loss of stability due to the increase in the durability of the asphalt mixture.

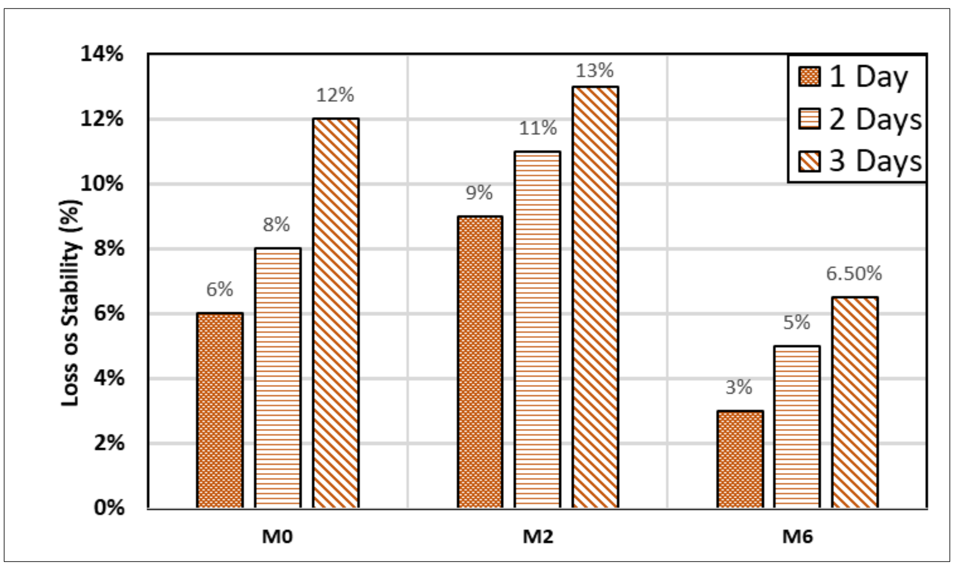


**Figure 15.** Loss of stability of asphalt mixes.

## 5.5. Rutting Results

A wheel loading test was used in the study to measure the rutting caused by a repeat bearing wheel. Figure 16 illustrates the results of the rutting depth for M0, M2, and M6. Based on the results of the study, M2 had the highest value for rutting depth, which was 8 mm, and M6 achieved the lowest value, which was 1.3 mm for rutting depth. The value for M2 increased by about 5.26%, and the rut depth of M6 decreased by about 82.9% compared with the control mix (M0). The decrease in the rutting depth results from 7.6 mm at M0 to 1.3 mm at M6 confirms the effect of adding polyethylene in improving rutting resistance because polyethylene is a kind of thermoplastic material with a high melting point, and these properties improve the binder stiffness, which may minimize asphalt deformation under repetitive wheel loading. The increase in the rutting depth results from 7.6 mm at M0 to 8.0 mm at M2 shows the effect of adding RAP, which deteriorates the rutting resistance.

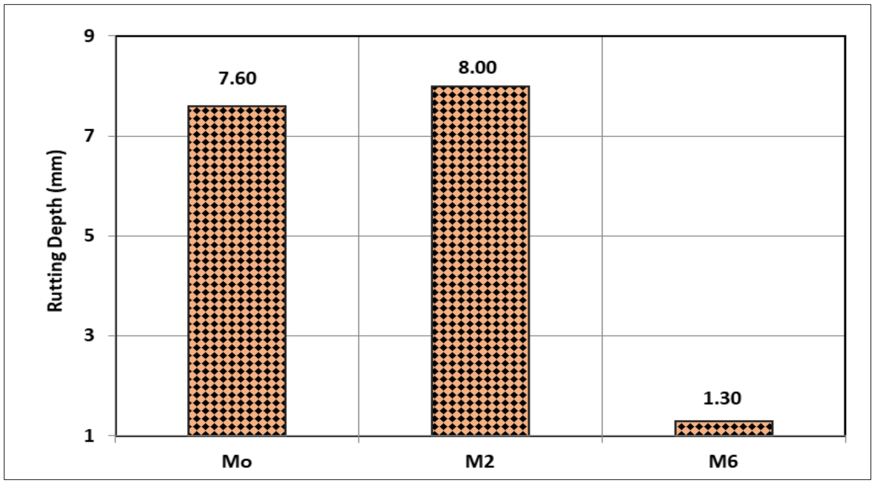


**Figure 16.** Rutting depth of asphalt mixes.

## 5.6. Indirect Tensile Strength Results

The tensile strength ratio (TSR) was used to measure the erosion resistance of the asphalt mixtures. The TSR results are illustrated in Figure 17. In light of the results, M2 had the highest value of the TSR ratio, which was 86.6%, and the lowest value of ITS in both cases, conditioned and unconditioned, compared with M0 and M6. This could be attributed to the effect of adding RAP without polyethylene instead of coarse aggregate. M6 had the lowest value of the TSR ratio, which was 80.7%, and the highest value of the ITS in both cases compared with M0 and M2; this shows the effect of adding polypropylene to mix with RAP.

Finally, adding RAP without polyethylene had the worst ITS values when in wet or dry states compared with the others, even though it had the highest percentage for the TSR. In contrast, adding polyethylene to mix with RAP increased the ITS values when in wet or dry states compared with the others, even though it got the lowest percentage for the TSR.

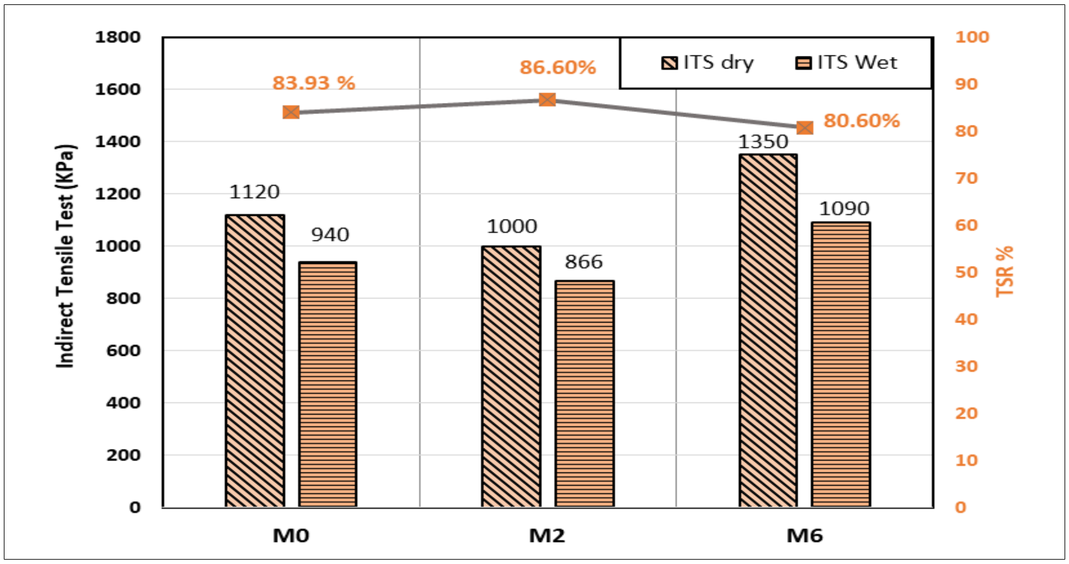


**Figure 17.** Tensile strength ratio of asphalt mixes.

## 6. CONCLUSIONS

From the previous experimental results for asphalt mixtures modified by RAP and percentages of polyethylene compared to control mix, the following can be concluded:

1. From using percentages of RAP (0, 25, 50, 75,100%) at adding bitumen content (4.4, 3.6, 3.56, 3.63, 3.64) % respectively .the percentage for bitumen content was decreased by about 18.63% With increasing proportions of RAP from 25% to 50% and by about 17.38% With increasing proportions of RAP from 75% to100%.
2. Stability results for mixtures containing percentages of RAP decreased about 21.68% With increasing proportions of RAP from 25% to 50% and by about 15.31% With increasing proportions of RAP from 75% to100%.while the stability values were increased about 10.62%

when used percentage of polyethylene (1 % , 2%) and by about 42.5% at percentage (3%,4%) polyethylene.

3. Bulk density values decreases with increasing proportions of RAP in the asphalt mixes compared with control mix. While the bulk density values increased with the percentage of polyethylene increased.
4. Values for flow increased when used percentage of RAP (50%, 75% and100%) except 25% the values decreased compared with control mix.
5. All asphalt mixes modified with RAP and percentage of polythelene achieved higher values for air voids than control mix. The highest air voids value was observed at 50% RAP content, while the highest of air voids value was observed at 1% polyethylene content.
6. Adding proportions of polyethylene to the mixtures greatly improves the properties of the mixture such as loss of stability, rutting and the indirect tensile strength.
7. Through the results it was found that the best percentage of RAP to be added as a modifier of asphalt mix was Found to be (50%) of the weight of the raw aggregate in the mixture.
8. The best polyethylene content to be added to the mixture to improve the properties was found to be (2%) instead of the weight of 50% reclaimed coarse aggregate in hot mix asphalt.

## 7. RECOMMENTATION

From the previous results and analysis, the following can be recommended:

- It is recommended to use recycled aggregates with percentages of polyethylene to improve the properties of the asphalt mixture and to preserve natural resources and protect the environment from its effects.
- It is necessary for the government and researchers to make an integrated plan for managing solid waste and making the best use of it to save raw resources.

## 8. REFERENCES

1. Hussain, A. and Yanjun, Q. 2012."Laboratory evaluation of asphalt mixtures containing various percentages of reclaimed asphalt pavement", Asian Journal of Natural & Applied Sciences, Vol. 1, No. 2, June
2. Federal Highway Administration. 2008. User Guidelines for Waste and By-product Materials in Pavement Construction. Washington, DC: FHWA.
3. Arshad, A. K., Karim, Z. A., Shaffie, E., Hashim, W., & Rahman, Z. A. 2017. Marshall Properties and Rutting Resistance of Hot Mix Asphalt with Variable Reclaimed Asphalt Pavement (RAP) Content. Paper Presented at the IOP Conference Series: Materials Science and Engineering.
4. Copeland, A. 2011. Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice. McLean, VA: Turner-Fairbank Highway Research Center, Report Number FHWA-HRT-11021.
5. Xiao, F., Su, N., Yao, S., Amirkhanian, S., & Wang, J. 2019. Performance Grades, Environmental and Economic Investigations of Reclaimed Asphalt Pavement Materials. Journal of Cleaner Production. 211: 1299-1312.
6. Taha, R., Ali, G., Basma, A., and Al-Turk, O. 1999. Evaluation of Reclaimed Asphalt Pavement Aggregate in Road Bases and Subbases. Transportation Research Record: Journal of the Transportation Research Board. No. 1652. Transportation Research Board of the National Academies, Washington, DC. 264-269.
7. Bennert, T., and Maher, A. 2005. The Development of a Performance Specification for Granular Base and

Subbase Material. Rutgers University, Piscataway, NJ.
8. Hassan Y. Ahmed, Ayman M. Othman, and Afaf A. Mahmoud, "Effect of using waste cement dust as a mineral filler on the mechanical properties of hot mix asphalt", Assuit University Bull. Environ. Res. Assuit EGYPT, Vol. 9 No. 1, March 2006.
9. AASHTO T-340 "Standard Method of Test for Determining the Rutting Susceptibility of Hot Mix Asphalt (APA) Using the Asphalt Pavement Analyzer", 2010
10. "Laboratory Tests Guide", General Authority for Roads, Bridges and Land Transport, Egypt, 2015