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The Effect of Rubber Crumbs on Marshall Properties for Warm Mix Asphalt

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ABSTRACT

A new pavement technology has been developed in Highway engineering: asphalt pavement production is less susceptible to oxidation and the consequent damages. The warm mix asphalt (WMA) is produced at a temperature of about (10-40) ^{o}C lower than the hot asphalt paving. This is done using one of the methods of producing a WMA. Although WMA's performance is rather good, according to previous studies, as it is less susceptible to oxidation, it is possible to modify some of its properties using different materials, including polymers. Waste tires of vehicles are one of the types of polymers because of their flexible properties. The production of HMA, WMA, and WMA modified with proportions of (1, 1.5, and 2%) of rubber crumbs by the dry method are accomplished in this work. Marshall Test and volumetric properties determination are performed to evaluate its performance. The results showed that using 1% of rubber crumbs as a replacement for fine aggregate in the warm asphalt mixture produced the best properties of the WMA compared to the conventional WMA.

Keywords: warm mix asphalt, crumb rubber, and dry method.

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تأثير فتات المطاط على خصائص مارشال للخليط الاسفلتي الدافئ

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الخلاصة

مع التطور الحاصل في هندسة الطرق تم استحداث تقنية تبليط جديدة وهي انتاج تبليط اسفلتي يكون اقل عرضة للاكسدة و ما يترتب عليها من اضرار. وهي التبليط الاسفلتي الدافئ الذي ينتج بحرارة اقل بحوالي (10–40) درجة مئوية من التبليط الاسفلتي الساخن، يتم ذلك باستخدام احدى طرق انتاج الخليط الاسفلتي الدافئ. الخليط الاسفلتي الدافئ بالرغم من ان اداءه جيد نوعا ما ،حسب دراسات سابقة كونه اقل عرضه للاكسده، الا انه من الممكن تعديل بعض خواصه باستخدام انواع مختلفه من المواد و منها البوليمرات. تعتبر نفايات اطارات المركبات احد انواع البوليمرات لما يتمتع به من خواص مرنة. استخدم في هذا البحث انتاج التبليط الاسفلتي ساخن ، تبليط اسفلتي دافئ و تبليط اسفلتي دافئ المعدل بنسب (1و 1.5 و 2) % من فتات المطاط بالطريقة الجافة. اجري فحص مارشال و تحديد الخواص الحجمية لتقييم اداءه. اظهرت النتائج ان نسبة 1% من فتات المطاط المستبدل من الركام الناعم في الخليط الاسفلتي الدافئ تنتج افضل خواص للخليط الاسفلتي الدافئ مقارنة بالخليط الاسفلتي الاعتيادي.

الكلمات الرئيسية: الخليط الاسفلتي الدافئ , فتات المطاط و الطريقة الجافة.

1. INTRODUCTION

Warm asphalt mixture is a new technology for producing asphalt pavement with a lower production temperature (mixing and compaction) than conventional pavement **(Albayati, 2018).** It is resulted by reducing the viscosity of the asphalt binder. The construction of warm asphalt pavement did not begin until the mid-1990s, so many researchers still do not sufficiently understand its long-term mechanical performance. Since that time, many researches and experiments have been conducted in the United States, Europe, and Germany to find out the behavior of this type of pavement **(Abdullah et al., 2014)**. The use of warm asphalt paving reduces the production temperature by about (10-40) Celsius than the temperature of production of conventional asphalt pavement, reduces the emission of harmful gases to the environment (as given in **Table 1.**), extends the pavement season, opens the road early for traffic, and reduces the oxidation of the asphalt binder. In addition, the use of warm mix asphalt with recycled tires rubber or other polymers and its use with recycled asphalt pavement **(Abdullah et al., 2014; Quintana et al., 2016). (Albayati et al., 2019)** this study showed that the warm prepared using industrial zeolite has a moisture sensor that is more sensitive than fraying because the zeolite contains an amount of water in its chemical composition. Warm asphalt mixture is produced using organic additives, chemical additives and foam technology **(Nikolaides et al., 2015).** Asphalt pavement causes types of failure such as rutting or fatigue cracks and other types, resulting from high loading of traffic on the asphalt pavement **(Ismael and Ahmed al., 2019)**. Unmodified asphalt binder may not perform satisfactorily and therefore this failure reduces the service life of asphalt pavement and increases maintenance costs. Therefore, many researchers recommended improving the properties of the asphalt binder by using different materials, including polymers, which may positively reflect on the functional performance of the asphalt pavement **(Gibreil et al., 2017; Lushinga et al., 2020)**. This approach consumes the waste of rubber tires and conserves the environment especially with the rapid growth in the number of vehicles**.**

Table 1. Emission reduction when the implementation of WMA **(Abdullah et al., 2014)**

Air Pollutant Gaseous	Reduction Measured as Compared to HMA (percent)
CO_2	15-40
SO_2	18-35
NO_X	18-70
CO	10-30
Dust	25-55

This means that rubber waste in the asphalt pavement industry makes it a sustainable material. Disposing of waste rubber tires is one of the environmental necessities because the waste produced by these wastes reduces the environmental space. Moreover, burning these wastes to dispose of them causes serious problems, as gases are emitted when burned. Therefore, there is an urgent need to recycle these wastes and use them for other purposes, such as improving the properties of asphalt pavement due to its elastic properties, as in some polymers **(Zhu et al., 2014)**. The use of crumb rubber asphalt began in the 1960s when it entered the interest of the asphalt pavement industry due to its elastic properties, which improve the skid resistance and durability of asphalt pavement **(Abdul Hassan et al., 2014)**. Rubber crumbs are prepared for use in asphalt paving by cutting the frame of the tire using a sharp knife, then washing it with water and leaving it exposed to air dry, then grinding and crushing it into small, irregular parts (as shown in **Fig. 1**), then the product is sieved to obtain required sizes crumbs rubber .The asphalt mixture modified with rubber crumbs is prepared by one of the methods, the wet method or the dry method. Wet method, in which fine rubber is mixed with hot asphalt for some time and at high speed, in which rubberized bitumen is obtained. The dry method is in which the hot aggregate is mixed with the rubber crumbs before adding the hot asphalt, where the rubber acts as an elastic aggregate (as shown in **Fig. 2**). When the load is applied, the rubber particles absorb the load and release it after removing the load **(Abdul Hassan et al., 2014; Colinas-Armijo et al., 2018)**. Rubber crumbs can adsorb asphalt binders (low molecular weight) components when in contact with asphalt. This causes the rubber particles to swell, so the asphalt binder contains materials with high molecular weight, which causes an increase in the viscosity of the asphalt binder.

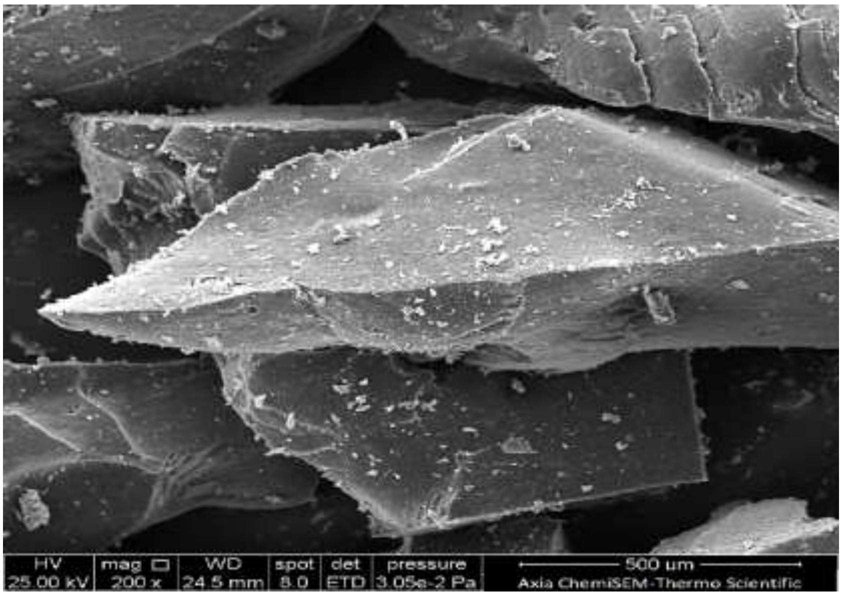

Figure 1. SEM (Scanning Electric Microscopy) image of rubber particles

Suppose this phenomenon is within limits that do not cause the loss of good asphalt properties, such as high viscosity which leads to the asphalt paving becoming brittle and prone to fracture. It has a good effect, such as increasing the thickness of the asphalt layer around the aggregate, so the pavement becomes more able to resist oxidation. To reduce the possibility of the appearance of the negative impact of absorbing asphalt oils by rubber. Using rubber with high penetration is recommended because it is rich in asphalt components. In addition, use a curing period in which the asphalt mixture is introduced in the loose state into the kiln and exposed to a temperature higher than the mixing temperature to eliminate the problem of swelling during compaction **(Abdul Hassan et al., 2014)**.

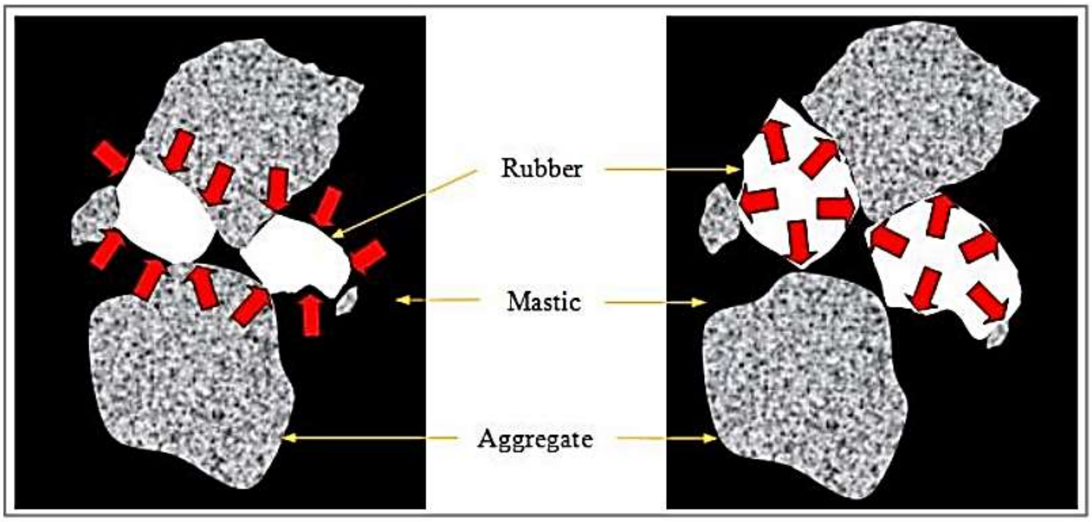

Figure 2. Rubber particles' elastic behavior before (left) and after (right) releasing the load **(Abdul Hassan et al., 2014)**.

Several studies showed that using rubber powder to modify the properties of asphalt pavement can improve the functional performance and increase the durability of the asphalt pavement, thus reducing the damage of this waste. (**Al-Qadi et al., 2016; Lushinga et al., 2020)**, this study used crumb rubber with asphalt mixture as fine and coarse aggregate. Marshall Test is carried out on the hot mixture modified with fine and coarse crumb rubber separately. The results were that the fine rubber used with asphalt mixture as fine aggregate improves the stability and flow of Marshall compared to coarse rubber crumbs. **(Bueno et al., 2014)** studied the use of rubber in micro surfacing and its effect on reducing noise and the performance of the asphalt pavement surface. It showed that adding rubber crumbs enhances the effect of vibration action between the surface and traffic.

This work aims to evaluate the effect of addition of rubber crumbs on the properties of the warm mix asphalt. Warm mix asphalt is prepared by adding 0.3% of synthetic zeolite. This warm asphalt mixture is modified by replaced (1%, 1.5% and 2% of the rubber crumbs by fine aggregates size of (2.36mm and 0.3mm). Marshall Samples are produced to test their volumetric and Marshall properties to determine how rubber crumbs effect on WMA properties.

2. MATERIALS

The raw materials used in this research to prepare the hot, warm, and warm asphalt mixture modified with crumb rubber. Laboratory tests will be conducted on them to know the suitability of these materials for this research.

2.1 Asphalt Cement

The asphalt link was brought from the Dora refinery, located south of Baghdad. Laboratory tests with grades (40-50) are conducted as given in **Table 2**.

Table 2. Physical properties of asphalt cement.

Property	ASTM Designation	Test result	SCRB specification
Penetration at 25 ^{O}C,100 gm, 5 sec. (0.1 mm)	D-5	47	(40-50)
Ductility at 25 ^{O}C, 5 cm/min. (cm)	D-113	145	>100
Flashpoint (Cleveland open cup), (^{O}C)	D-92	321	Min.232
The softening point (^{O}C)	D-36	56	------------
Viscosity @ 135 °C, c.p	D-4402	450	Min.400
Viscosity @ 165 °C, c.p	D-4402	135	---------
Specific gravity at 25 ^{O}C	D-70	1.03	---------

2.2 Aggregate

The aggregate used in this work (illustrated in **Table 3.**) is a crushed aggregate with a small amount of rounded aggregate produced from the Al-Nibaie quarry located north of Baghdad. The used aggregates satisfy the specifications of fine and coarse aggregates to meet binder course gradation as required by the State Corporation of Roads and Bridges **(SCRB(R9/2003).**

Table 3. The physical properties of the aggregate

Property	ASTM Designation	Coarse aggregate	Fine aggregate	Specification
Bulk Specific Gravity	C-127, C-128	2.613	2.621	-
Apparent Specific Gravity	C-127 , C-128	2.673	2.688	-
Percent Water Absorption	C-127 , C-128	0.91	0.94	-
Toughness, by (Los Angeles Abrasion)	C-131	20.8%	-	Max. 35%
Soundness loss by sodium sulfate solution%	C-88	4.1 %	-	Max 12 %

2.3 Mineral Filler

This work uses Portland cement, which is available locally, as a filler. It was obtained from Al-Mas Company-Iraq. **Table 4.** Presents the physical properties of Portland cement that passed through sieve No. 200 (0.075 mm).

Table 4. The physical properties of Portland cement

Property	Result
specific gravity	3.15
Passing Sieve No.200 (0.075 mm)	97%

2.4 Aspha-min (Zeolite)

Zeolite is a white powdery substance that was added in proportions of 0.3 of the total mass of the asphalt mixture as an additive to produce warm asphalt mixes. The imported zeolite has physical and chemical properties according to the information from the manufacture; as given in **Table 5**.

2.5 Waste Tire Rubber (WTR)

Black colored rubber crumbs of specific gravity of 1.15 are brought from Al-Kut Towers Company (Al-Diwaniyah Tires Factory) affiliated with the Iraqi Ministry of Industry and Minerals. The ratios 1%, 1.5%, and 2% of the total mass of the asphalt mixture were used, and the fine aggregate was replaced with a size NO.8 and NO.50.

3. SELECTION AGGREGATE GRADATION

According to the Iraqi State Corporation for Roads and Bridges (SCRB), the maximum size of the aggregate selected for the aggregate gradation used in asphalt concrete mix for the laboratory specimens for the binder course was 25.0 mm, as shown in **Fig. 3**.

Table 5. Physical and chemical properties of WMA additive, zeolite:

Property	Results
ingredients	$Na_2O.\ Al_2O_3.2\ SiO_2$ (Sodium Aluminosilicate)
SiO_2	32.8%
Al_2O_3	29.1%
Na_2O	16.1%
LOl	21.2%
Physical state	Granular powder
Color	White
Odor	Odorless
Specific gravity	2.03

- According to the data sheet attached to it, when imported.

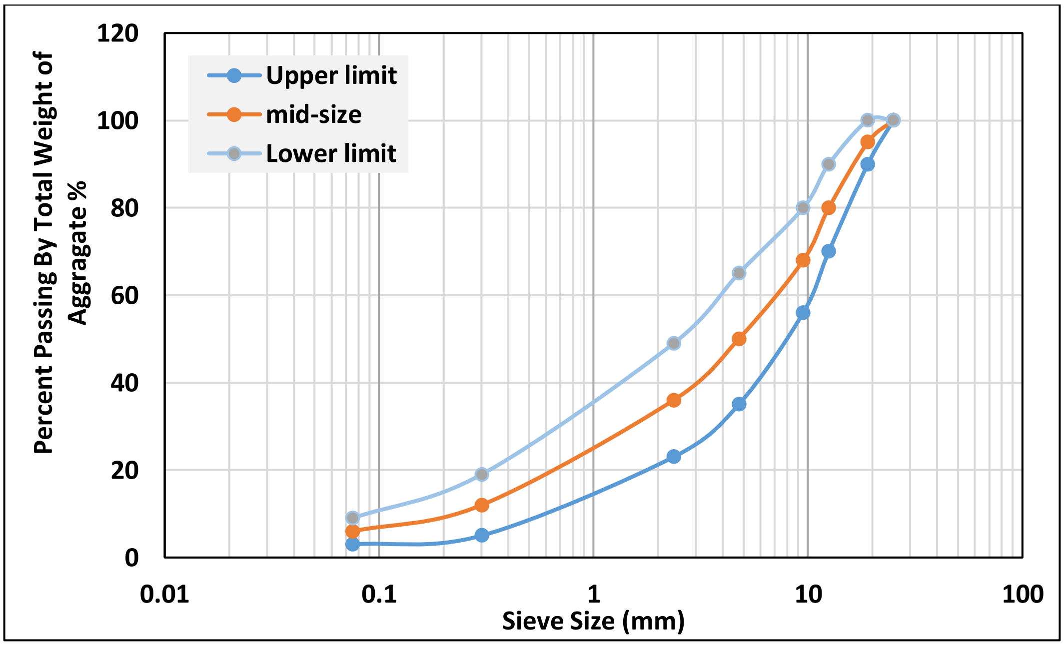

Figure 3. Gradation curves of an aggregate for binder coarse

4. MIX DESIGN

Using laboratory materials conforming to Iraqi specifications, State Corporation of Roads and Bridges (SCRB (R9/2003), Marshall samples were prepared by measuring (4*2.5)in **(ASTM D 6926-10 2010).** Hot asphalt mixture that was prepared with a mixing viscosity of 170 ± 20 cP (0.17 ± 0.02 Pa.s) and compaction viscosity of 280 ± 30 cP (0.28 ± 0.03 Pa.s), respectively and in accordance with **ASTM D4402,** as shown in **Fig. 4.** Samples of the warm asphalt mixture prepared 0.3% by the total weight of the mixture of synthetic zeolite was produced with a mixing temperature (120-115) C and a compacting temperature of (110-115) C. Use asphalt content percent (4,4.3,4.6 and 4.9)%, that produces the optimum asphalt content 4.5% of HMA and 4.45% of WMA. The warm asphalt mixture was prepared by replacing the fine aggregate (NO.8 and NO.50) with (1, 1.5, and 2) % of the aggregate's total weight with the same size rubber crumbs where higher proportions of asphalt were used than the traditional mix, namely (4.5, 5, 5.5, 6 and 6.5) %. To find the optimum asphalt content of the warm asphalt mixture modified with (1, 1.5, and 2) % rubber crumbs, the optimum asphalt content was (5, 5.4, and 5.6) % sequentially. **Fig. 5** shows the preparation of the WAM modified by rubber crumbs.

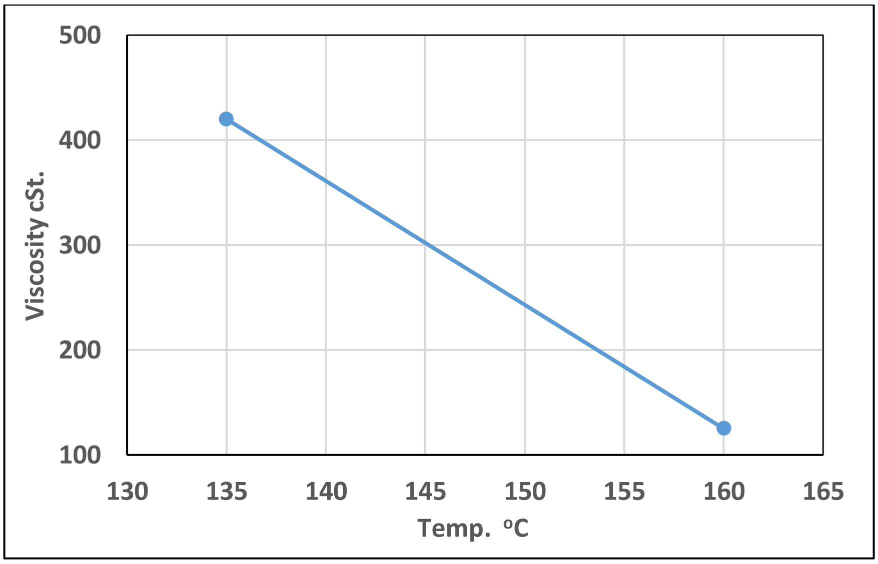

Figure 4. Viscosity-Temperature Chart for Asphalt Cement (40-50)

Figure 5. The work stage of WMA modified by CR: A) hot aggregate, B) addition of CR to a heated aggregate, C) speared zeolite on dry materials, and D) adding asphalt cement.

5. PREPARATION OF SAMPLES FOR THE MARSHALL TEST

After designing the asphalt mixtures used in this research, samples were prepared to conduct a Marshall test on them and to know the performance of these mixtures by measuring the stability and flow of Marshall in addition to determining their volumetric properties.

6. RESULTS AND DISCUSSION

Marshall Test results showed that the optimum asphalt content, as shown in **Fig. 6,** significantly increased the asphalt content compared with the conventional asphalt mixture. As a result, it appears as a reaction to reduce the absorption of rubber crumbs for aromatic asphalt oils, and thus rubber swells. Marshall Stability presented in **Fig. 7** showed that 1% of crumb rubber produces a significant increase in stability. It results from increased asphalt viscosity, which increases the adhesion between aggregate particles. However, as the percentage of additional crumb rubber increases, this adhesion gradually decreases, and the negative effect becomes visible as the asphalt mixture loses its adhesion strength. The flow shown in **Fig. 8** The increase in Marshall Flow indicates a rise in the Marshall specimen's deformation under exciting loads. The percentage of asphalt content rising is the cause of this increase. However, the increase in crumb rubber content leads to a departure from (**SCRB, 2003**). **Fig. 9** shows the density of asphalt mixtures used. The density of WMA decreased compared to the HMA due to the use of synthetic zeolite containing a percentage of water in its chemical composition.

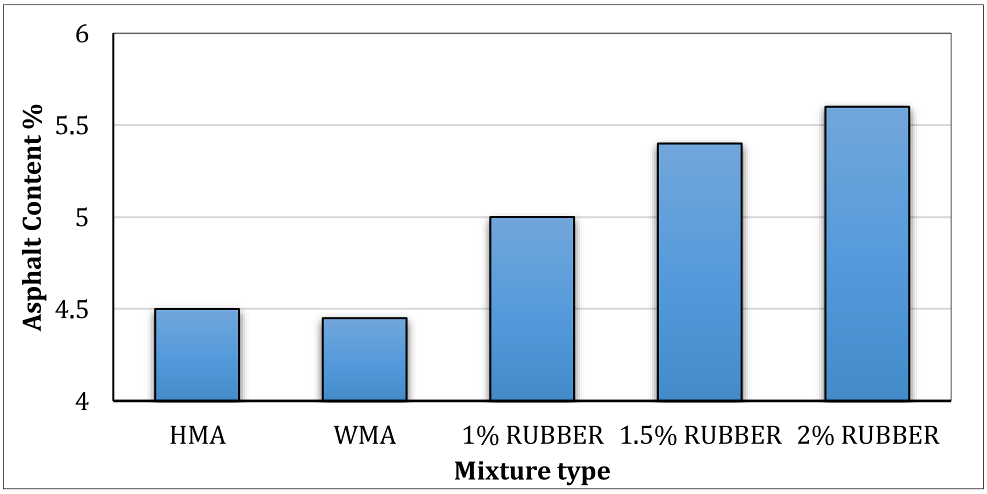

Figure 6. Relationship between asphalt mixtures type and asphalt content

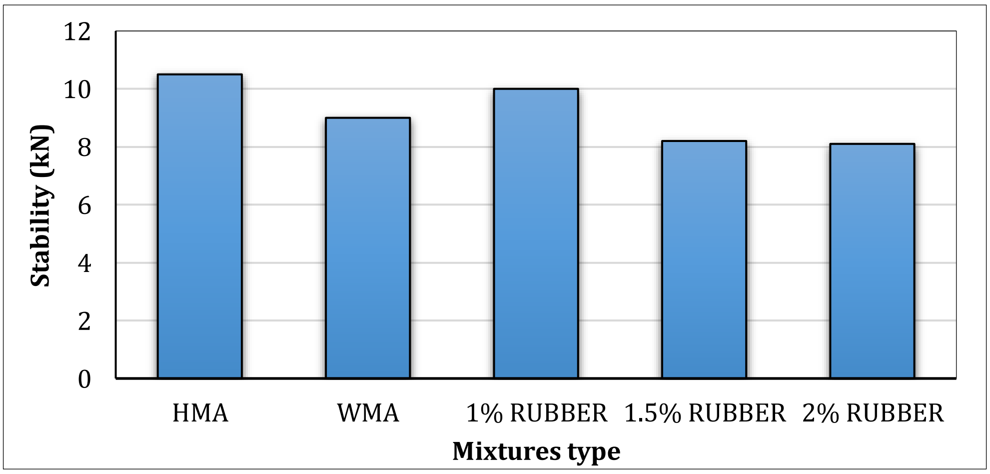

Figure 7. Relationship between asphalt mixtures and stability

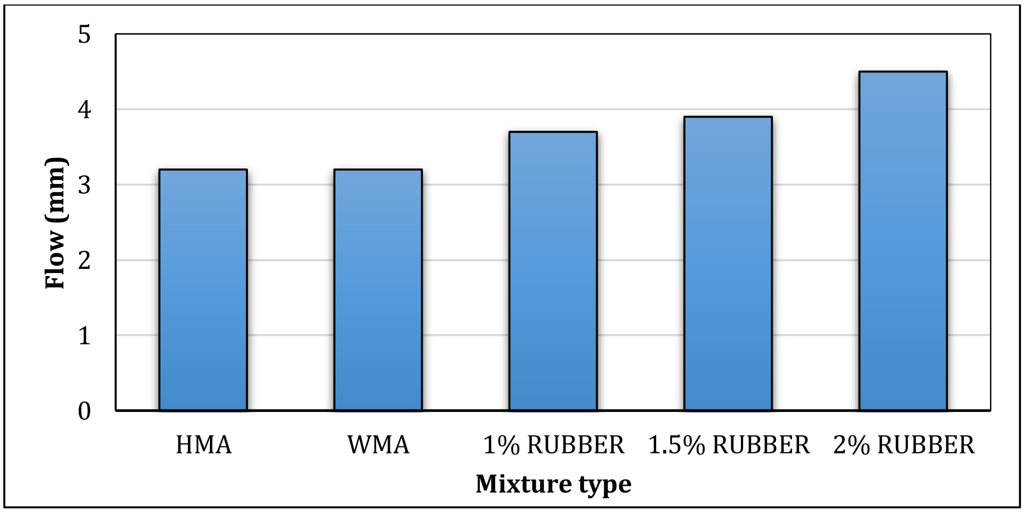

Figure 8. Relationship between asphalt mixtures and flow

When the water evaporates, it causes a density reduction. Reduction in the density of asphalt mixtures modified by crumb rubber is related to higher optimum asphalt contents of these crumb rubber mixtures and increased CR content. As for the air voids and the void in mineral aggregates, **Figs. 10 and 11**, which were found by using Eq.s. (1 and 2) notice a decrease and then an increase with the increase in rubber content.

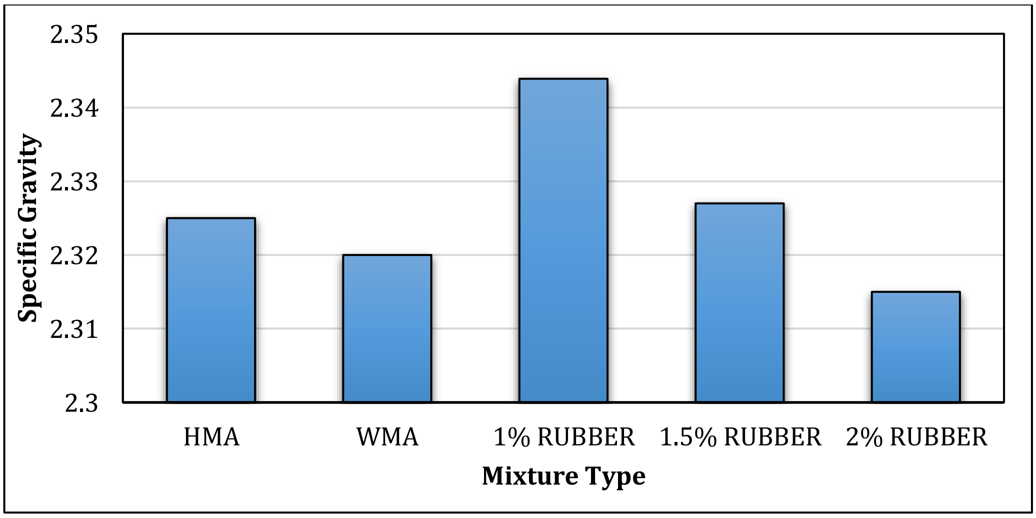

Figure 9. Relationship between asphalt mixtures and density

As for the void filled with asphalt in **Fig. 12** that was found using Eq. (3), it increases by increasing the rubber crumbs and then decreases. As a result, when rubber crumbs are added to the asphalt mixture, it absorbs the aromatic oils contained within the chemical composition of the asphalt binder. Thus the viscosity of the asphalt increases, causing an increase in the thickness of the asphalt film surrounding the aggregate particles; this causes a decrease in *AV* and *VMA* and an increase in *VFA*. However, with an increase in rubber content, the opposite effect occurs.

$$AV\% = \left(\frac{(Gmm - Gmb)}{Gmm}\right) \times 100 \quad (1)$$

$$VMA\% = \left(100 - \left(\frac{Gmb \times Ps}{Gsb}\right)\right) \times 100 \quad (2)$$

$$VFA\% = \left(\frac{VMA - AV}{VMA}\right) \times 100 \quad (3)$$

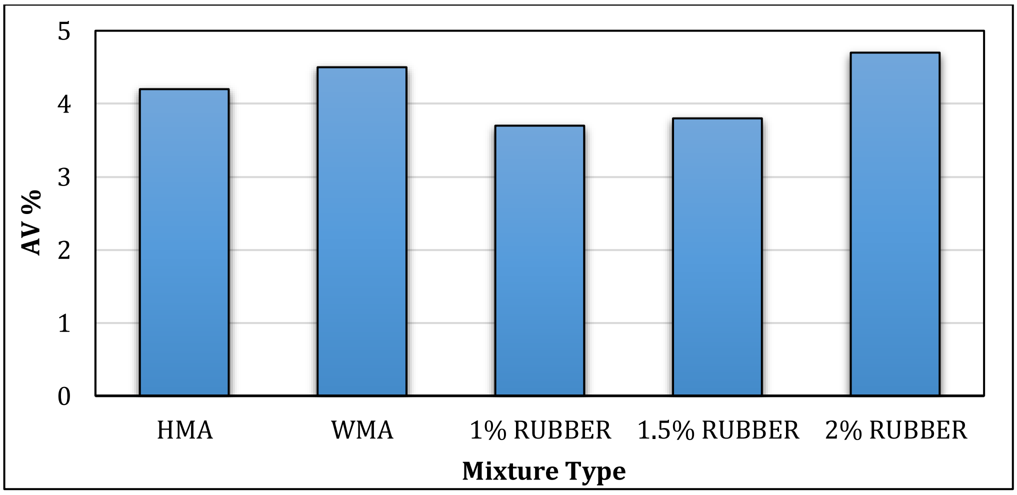

Figure 10. Relationship between asphalt mixtures and air voids

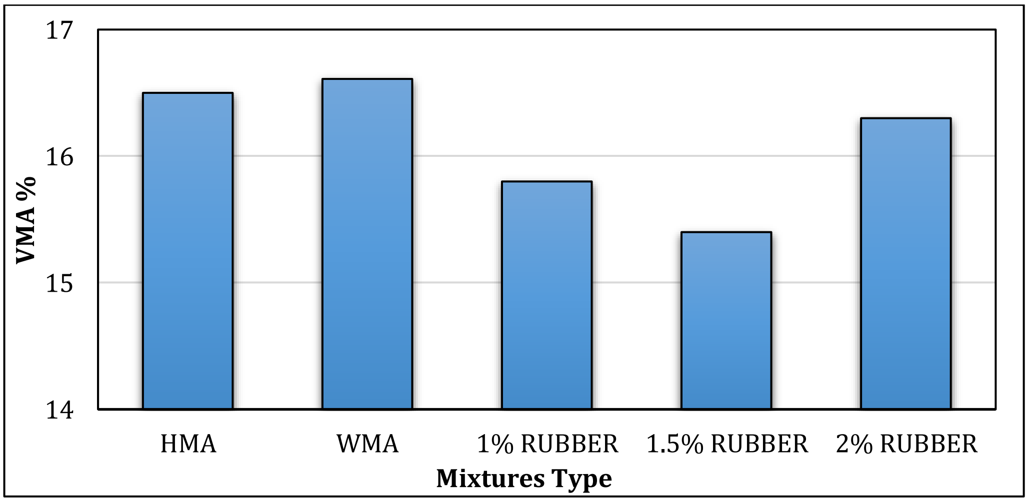

Figure 11. Relationship between asphalt mixtures and *VMA.*

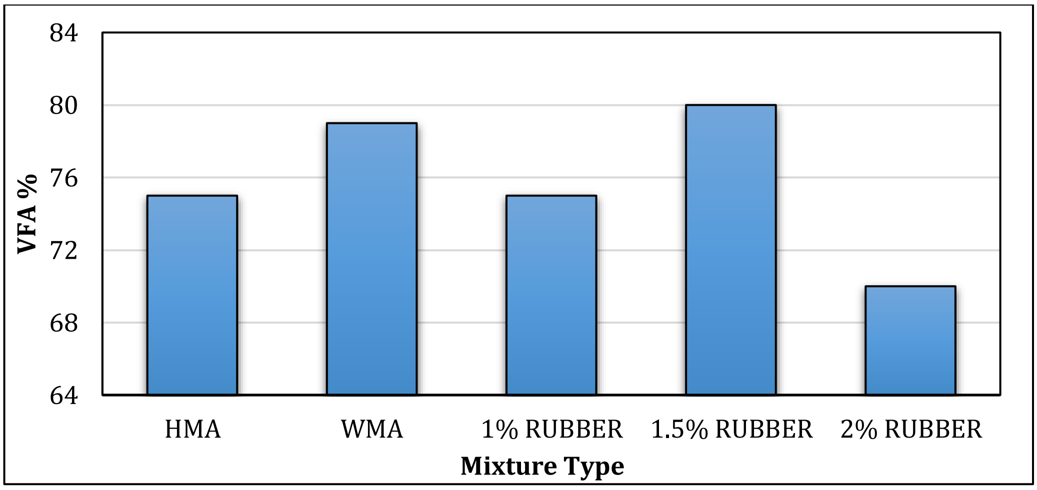

Figure 12. Relationship between asphalt mixtures and *VFA*

7. CONCLUSIONS

After conducting a Marshall Test on the asphalt mixtures used in this work, HMA, WMA, and WMA modified by crumb rubber, and evaluating their volumetric properties, the following was concluded:

1. Increasing the optimum percentage of asphalt by increasing the added rubber content reduces the damage caused by the absorption of aromatic asphalt oils and swelling, which may cause a decrease in the cohesion of the asphalt pavement.
2. 1% is the optimum rubber content that produced the best properties of the warm asphalt mixture modified with crumb rubber.
3. 1% is the optimum rubber content that significantly increased the Marshall stability compared to the conventional warm asphalt mixture.
4. The air voids and the void in mineral aggregates decrease with increasing the content of rubber crumbs and then increase.
5. The void filled with asphalt increase with increasing rubber crumb content and then decrease.
6. Increasing the optimum asphalt content in the asphalt mixture compensates for using a high-penetration asphalt gradient.
7. It is necessary to have a maturation period in which the asphalt mixture, which is in a loose state, is introduced into the oven and exposed to high heat for some time to get rid of the negative effect of swelling of rubber crumbs during compaction, which causes loss of cohesion of the asphalt paving.

NOMENCLATURE

AC: Asphalt Cement

ASTM: American Society for Testing and Materials

AV: Air Voids

CRM: Crumb Rubber Mixture

Gmb: bulk specific gravity of paving mixture.

Gmm: Maximum theoretical specific gravity of paving mixture.

Gsb = bulk (dry) specific gravity of the aggregate
HMA: Hot Mix Asphalt
OAC: Optimum Asphalt Content
SCRB: State Corporation of Roads and Bridges
PS: aggregate as a percentage of total mix weight.
VFA: Voids Filled with Asphalt
VMA: Voids in Mineral Aggregate
WTR: Waste Tire Rubber
WMA: Warm Mix Asphalt
SEM: scanning Electric Microscopy

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