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Studying the Sustainable Performance of Hot Asphaltic Mixtures Modified by Crumb Rubber

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ABSTRACT

Roads are exposed to different temperatures and friction conditions. Production of highly efficient, flexible pavement needs solution of the problems of rutting, aging, and cracks after long operational times and climate changes. Using recycled material is one of the significant aspects of a sustainable road production process. Rubber has the advantage of keeping its nature under high temperatures and radiation. In Egypt, the climate has undergone a big change with unexpectedly high temperatures in the last few years, mainly in the south of the country. Adding Crumb Rubber CR to the hot mixture affects its weathering opposition and aging properties. It concentrates on the exposure of the tested specimens to Ultraviolet (UV) radiation for different periods of time. The rubber is a recycled or wasted rubber material (powder and crumb rubber). Also, it includes a review of practical trials on many sites. This paper aims to study the effect of CR on the aging performance of an asphalt mixture for a wearing surface layer with two types of hot mixtures. The first is an aggregate with a modified bitumen binder (10% of the weight of bitumen), and the second is using rubber for 2% of the whole weight of the mixture with unmodified bitumen. Specimens are subjected to UV for different periods of time. The results conclude that both ductilities decrease by 38% and 40% for types A and B; respectively. The penetration values are 28.21 and 12.78 for types A and B, which indicate the high sustainable performance of type A against temperature in the natural case and after time exposure. Also, the ductility of type A is greater than type B for all exposure times. So, it can be concluded that type A has higher temperature stiffness than type B and is suitable for use in countries with high temperatures. This study will help policy makers in choosing the perfect percentage of additions especially in hot regions.

Keywords: Recycled material, hot mix asphalt, aging performance, UV tests, CR wasted material, Marshall Test

1 INTRODUCTION

Continually increasing traffic flow and changing temperatures because many problems on the surface layer of the flexible pavement, such as rutting, longitudinal cracks, and thermal cracks. Flexible pavement is defined as a pavement layer comprising of a mixture of aggregates and bitumen heated and mixed properly and then placed with compaction on a bed of granular layer. Major highways are constructed with bituminous surfacing. 86 % of rural highways and 78 % of urban roads are of flexible type (Chandra, 2017). The required properties of the asphaltic mixtures are stability against stresses, flexibility, and skid resistance that make the surface stable under the turned tires of a car, durability under mechanical and thermal stresses that are controlled by the percent of bitumen in the mix to cover the aggregate, and finally, the sustainability by using a recycled material with the available and cost-effective feature (Ford S., 2015).

Different kinds of pavement have different performance levels depending on the properties of the asphaltic mixture and its additions. When the technology is cost-effective, people try to get the most benefits from it. From an economic feature, it is better to achieve higher performance for the asphaltic mixture at a low cost. Various additives have been utilized to improve the temperature characteristics of bitumen compositions as well as their durability and toughness.

One of the most popular wastes against high temperatures is wasted rubber from the tires of cars or trucks. About one billion tires are damaged each year and stored in a landfill which increases pollution by insects (Tsang H., 2016; Waste Management World, 2010; Ferronato N., 2019). The first trial of using the recycled rubber was in Holland, 1929, and in United States of America, 1974 (Dondi, G. T., 2014). From 1960 to 1995, MacDonald Ch. made a lot of practical using of rubber in more than 400 projects on California roads because of the economic and environmental benefits (Ashphalt Rubber Usage Guide, 2003). For the last decade, there have been many studies of the weathering effect on asphalt behavior (Hu J.,2018; Zhou T, 2021).

1.1 Rubber material recycling procedure

In rubber material recycling, direct or processed waste rubber products are used. Recycling methods include retreading, waste rubber disposal through pyrolysis, and grinding of tires or other rubber products. The cryogenic process is the most popular and begins with the fragmentation of used tires and steel removal. The following step consists of the application of liquid nitrogen to the pieces of tires obtained from the previous step in the cryogenic tunneling. Then, the frozen pieces of tires are carried to the granulators, where the crumb rubber is obtained with a given grain size distribution. The final step of the cryogenic process consists of the removal of textile and steel fibers (Ilvrano A. et al., 2014).

There are two major retreading techniques after the tyre is retread and its characteristics restored; cold or hot. The life of tires extends of about an additional 150,000 km service after recycling process (McNally T., 2011). The different granular sizes of recycled tires allow for wide use of rubber waste as a respected component of composite materials in any economy. Crumb Rubber Modified (CRM) asphalt binder was used in the asphalt pavement and presented a good high-temperature performance in the laboratory (Cheng Y., 2018). Also, asphalt-rubber Gap-Graded AR-Ga) mix as a pavement material has gained benefits by enhancing its performance. It composed of at least 15% rubber by weight of the total asphalt binder (Venudharan V., 2016).

Many studies used polymers or rubber to enhance the asphaltic properties. It is particularly beneficial to use rubber from recycled tires in the road construction industry to modify the properties of asphalt mixtures. Crumb rubber from scrap tires is an excellent alternative to polymers used as bitumen modifiers from mechanical and economic aspects (Zhu J., 2014). The performance improvement of rubber asphalt pavements in the field has been tested and has given noticeable results (Way, 2011). *Yusif M.* evaluated the effect of fine and coarse rubber particles on rutting performance. He concludes that the 3.5% of coarse rubber particles increase the rutting resistance of Hot Asphalt Mixture HAM (Yusif M., 2015). The difference between using gap or dense gradation (Dondi, 2014); (Saha, 2015) ensured a positive effect in both type of degradation. Another study confirmed that it also improved performance in extreme climatic conditions under heavy traffic condition (Shubham B., 2017).

In an application on the high-temperature cities, Shuwaikh city, the Kuwait Institute for Scientific Research, carried out the first experiment to pave a road using rubber asphalt technology (KISR, 2019). The new technology relies on mixing asphalt & aggregate with rubber and taken from the offcuts of damaged tires that were used on highways in the American state of Arizona during the sixties of the last century because of its high thickness and its huge ability to absorb the noise resulting from traffic in those roads. They made three sections of the road with different rubber types. Also, they made a comparison of performances of the three experimental sections with the passage of time, and exposure to loads, and weather factors regarding the resistance of asphalt mixtures to cracks and rutting. Also, they evaluated changes in the stiffness of each section, using the Falling Weight Deflectometer instrument (Omar S., 2019).

In practical studies, the optimum percentage of CR content is determined. Azawee et al. proved that the optimum percentage of rubber in the bitumen binder added to the mix shouldn’t exceed 10% of the asphalt content (Esraa T., 2018). They tested many concentrations of CR, from 2% to 12% of the weight of bitumen, and compared the mechanical properties of the resulting mixtures to reach the optimum concentration.

From a sustainability environment aspect, *Paje et al.* tested many road segments with several rubber-bitumen binders' concentrations. the results showed that modified mixtures made by wet process with a modified rubber-bitumen binder reduced noise by a factor of one, while mixtures made by dry method reduced noise by about 0.5 dB and mixtures made by dry process reduced noise by 2 dB(PAJE S.E, 2010).

Also, rubber can be added to the asphalt mixtures as a percentage of the total mixture weight. Many studies used this method and studied the enhanced properties. Nguyen and Tran examined the effects of Crumb Rubber CR content on the engineering properties and determined the optimal content in the mixture. They increased the rubber content from 0 to 3% gradually. They observed that a rubber content of 1.5-2% was the optimum (Nguyan H., 2018). The performance positively correlated with curing time from 0-5 hours.

Sajed Y. at el. evaluated the effect of coarse and fine rubber particles on the rutting performance of hot asphalt mixture (HAM). The coarse rubber particles exhibit increased rutting resistance as the percentage of rubber increase up to (3.5% of the bitumen weight). On the other hand, crumb rubber dissolved in the binder and stiffened to increase its rutting resistance. Only up to (2.5%) of coarse rubber particles could be used as compared to (15%) of crumb rubber (Sajed Y. ,2013).

Bitumen has oily nature; when covering a rubber particle, oil is absorbed by rubber, which increases the viscosity and anti-cracking characteristics of the resulting bitumen (Dantas, Pais, Farias, & Pereira, 2014). It has been used in Texas since 1989 (Takallou H.B., 2003) with sequential stages. According to previous findings, when adding crumb rubber, the low-temperature performance, skid resistance, and fatigue properties of modified asphalt have been improved. Additionally, adding crumb rubber significantly improved the rutting resistance and moisture susceptibility of asphalt mixture and even long-term pavement service performance characteristics, such as driving safety and comfort (Bansal Sh., 2017). Results show that the addition of rubber leads to a reduction of specific heat for the rubber-modified binders. At all temperatures above 25°C, aged samples have lower thermal conductivity than the un-aged ones (Zadshira M., 2020). UV aging evaluation system is desirable for highway construction in areas exposed to high UV radiation.

1.2 Ultraviolet UV accelerated aging test

One of the main factors affecting the quality of asphalt is its anti-aging performance. In the different structural layers of asphalt pavement, the aging behavior of asphalt is relatively different (Wang, F. et al., 2014& 2020). The external temperature and traffic load affect only the upper layer, but solar radiation causes voids in asphalt pavements. It can affect the surface to a depth of about 1 cm (Chen, Z.H. et al, 2020). The results found that UV radiation seriously destroys the network structure formed by the cross-linking effect in SBS-modified asphalt binders. This aggravates the degradation of SBS and results in a great change of rheological properties after UV aging impact of Ultraviolet Radiation on the Aging Properties of SBS-Modified Asphalt Binders (Huanan Yu et al., 2019). Binders with low-temperature ductility are highly sensitive to UV aging (Zou l. 2021).

From the previous review, recycled rubber materials and their properties were examined. Some of them were classified into chemical interaction, and others are physical or mechanical. The primary purpose of using rubber as a modification in asphaltic mixtures is to increase the viscosity at high temperatures, refine the flexibility and elasticity of binders at low temperatures, improve the adhesion to aggregates, and improve high thermo-stability and aging resistance. In this study, the dry process is used to make good asphalt mixtures and compare different particle sizes that were used to estimate its impact on the mechanical characteristics of the asphaltic mixture. The modified asphalt composite was prepared in the laboratory with crumb rubber added to produce two kinds of mixtures.

A designed un-modified asphalt mixture of granular aggregate, bitumen, and filler was tested using Marshal Test to reach the net value of bitumen suitable percent from its mass weight. When blending with a rubber modifier, it produces a mixture characterized by a well dispersed modifier that is stable at high temperatures. Each bitumen, rubber, and aggregate has a chemical and physical nature that makes the mixture have different characteristics and performance with temperature, loading, and repeated loads. Here, a dry process is used to make the asphalt mixture with several. Tests for materials and resulting mixtures are made to describe the impact of adding CR and illustrated in the results.

Previous studies proved that the additions improve the aging properties of the modified asphalt with no consideration of the technique of addition. This study aims at using two types of rubber material in addition to studying the aging properties of each type. The types of tests for aging indications were penetration and ductility. The present study investigates the effect of adding CR to the hot mixture on its weathering opposition. The rubber used is recycled or waste rubber material, powder and crumb rubber. Also, it includes a review of practical trials on many sites. As increase in CR percent for both kinds of mixtures as the mechanical properties enhance the rubber addition (Nguyan H., 2018). The percent was chosen to be an average percentage from the previous study. As the percentages, (2% of the whole weight and 10% of the bitumen) gave nearest values of stability and flow in Marshall Test, it is proposed to be base mixtures for the aging testing. The paper aims to study the effect of crumb rubber on the performance of an asphalt mixture for a wearing coarse layer with two types of hot mixtures. The first is an aggregate with a modified bitumen binder (10% of the weight of the bitumen), and the second is rubber as an aggregate (2% of the whole weight of the mixture) with normal bitumen. The following paragraphs describe the physical properties tested for the used materials.

2 TESTED MATERIALS AND PROPERTIES

The study includes practical work as tests to demonstrate the physical properties of the bitumen, crumb rubber CR, and aggregate as follows:

2.1 Bituminous material properties

The bituminous material used in this study had a penetration grade of 60-70 percent and a specific gravity of 1.02, and it came from a U-turn highway construction site on the 30 km Al-Ismailia-Port Said highway. For determining the physical characteristics of the base bitumen, penetration, softening point, viscosity, flash point, and ductility tests were performed in the laboratory of Port Said University, and the results are shown in Table (1).

Table (1): Properties of asphalt cement.

Test	AASHTO Designation No.	Results	Specification limits
Penetration (0.1 mm, 25°C, 100 gm, 5 sec.)	T-49	63	60-70
Softening point (ring and ball test, °C)	T-53	53	45-55
Flash point (°C)	T-48	275	≥ 250
Kinematic viscosity (centistokes, 135 °C)	T-201	345	≥ 320
Ductility, cm.	T-51	+10	≥ 95

2.2 Rubber material properties

After making gradation on the laboratory sieves, there are three particle sizes; powder retaining on sieve no.100 (0.300 mm), crumb-R 1 retaining on sieve no.8 (2.63 mm), crumb-R 2 retaining on sieve no.4 (4.75 mm). All sizes are added together to make both mixtures, as shown in Figure (1) of the practical work part. The physical and chemical parameters of crumb rubber are illustrated in Table 2.

Table (2): Physical and chemical parameters of crumb rubber.

Properties	**Values**	**Specifications**
Density (gm/cm^3)	1.15	1.10-1.30
Moisture content (%)	0.45	<1.0
Metal content (%)	0.023	<0.05
Fiber content (%)	0.55	<1.0
Ash content (%)	4.6	≤ 8
Acetone extract (%)	15	≤ 22
Carbon black content (%)	32	≤ 28

Source: Hana Masr ELdawlia for Reclaim Rubber, Industrial Area 2, 002 Ismailia, Egypt

2.3 Aggregate properties

Crushed dolomite obtained from "ATAKA" quarry of Suez was used as coarse and fine aggregate. A water absorption test and Los Angeles abrasion test were conducted on crushed dolomite. A dense gradation was tested in this study as a wearing surface layer. A 4-c gradation was used in this search. Results for asphalt mixture designed gradation and aggregate qualification tests are illustrated later in results section.

3 PRACTICAL WORKS

3.1 Preparing of un-modified asphaltic mixture (base case)

Preparing specimens for the Marshall Test is conducted with varying percentages of bitumen (4%, 5%, 6%, and 7%) by weight of mineral aggregate from the graded design, which called the optimization process according to *ASTM T-11*. Three specimens were prepared for each percent. The asphalt mixture preparation steps were performed for the formulation of compacted specimens, as shown in Figure (2). Stability, flow, bulk density, and air voids resulting from Marshall Test are illustrated in the results and discussion part. Marshall Test designs a criterion for a heavy traffic classification and is shown in Table (3) according to *AASHTO D 1559* standards.

Figure (1): The crumb rubber material (CR)

Figure (2): Preparing the specimen for Marshall Test

Table (3): Properties of Marshall asphalt mixtures

Traffic category	**Heavy & very heavy traffic**	
Stability(ibs)	1500	
No. of compaction blows	75	
Test property	**Min**	**Max**
Flow (0.25 mm (0.01 inch))	8	16
% voids	3	5
% voids with bitumen	65	75

3.2 Preparing the modified rubber-asphaltic mixtures

Marshall Test for the modified asphaltic mixtures was prepared again by adding varying percentages of rubber, one as 2% of the bitumen weight and again for three percentages of the whole mix. The first type (A) of addition is tested by adding 5%, 10%, and 15% of the bitumen to make modified bitumen and then making steps of the hot mix. The second type (B) has been made after making a sieve analysis with the same sieve size (reducing the rubber weight from the weight of aggregate retained on the same sieve). After being heated in a hot oven, heated bitumen, aggregate, and rubber are stirred with a manual stirrer for approximately half an hour at 150°C. Specimens were prepared in the laboratory at mixing temperatures ranging from 140°C to 160°C for mixtures incorporating, yielding twelve specimens for the base mixture.

Rubber has the advantage of keeping its nature under high temperatures (Mastrall et al., 1996). Crumb rubber was added to hot aggregates before mixing at optimum binder content in the dry process to reach 1200 gm. For both types, the percentages that give the nearest values of stability and flow are chosen to be base mixtures, which are 10% of the weight of bitumen (type A), and 2% of the whole weight of the mixture (type B). Three specimens were prepared for each type of mixture to indicate the impact of additions. Results are discussed in the comparisons section. Many tests have been considered adequate to clarify the effects of rubber materials on asphalt mixtures. Marshall Stability and flow tests were repeated on the reference and rubber-asphalt samples, and UV penetration and ductility tests were executed before and after exposure.

3.3 Preparing the modified rubber-asphaltic mixtures for Marshall Test

ASTM D6114M-09 standard for CR-modified binder suggests that the rubber-modified binder should have a percentage of binder weight, which can be calculated by:

$$\%\text{wt.} = \frac{\text{Weight of crumb rubber}}{\text{Weight of crumb rubber} + \text{weight of neat binder}} \qquad (1)$$

Some other binders use the percent of the bitumen (Saha, 2015). So, two types of asphalt are used, one with 5%, 10%, and 15% of the weight of bitumen (type A), and the second with rubber as an aggregate with 2% of the whole weight of the mixture (type B) (Nguyan H., 2018). Nine specimens were made for each type of mixture. UV tests had been made for the modified specimens to find the anti-aging behavior for one, two, and three months to simulate the aging development process of asphalt under UV light irradiation.

3.4 Preparing the modified rubber-asphaltic mixtures for UV aging test

Sixteen specimens are prepared for each UV exposure test, and the tests conclude with four specimens from each type A and type B. So, UV tests were made for the modified specimens to find the anti-aging behavior for one, two, and three months to simulate the aging development process of asphalt under UV light irradiation.

The asphalt sample container used in the indoor accelerated UV aging test is divided into sampling and preparation of modified or unmodified asphalt (JTG E20-2011). First, asphalt with a mass of 11.30 ± 0.5 g was put into the sample dish and then heated to 135 ± 1 °C, ensuring that it was evenly spread in the container. Figure (3) shows the asphalt sample used for the UV aging test is shown in. The surface temperature of asphalt pavements can reach 60 °C. Thus, 60°C was selected as the temperature for the accelerated UV aging test.

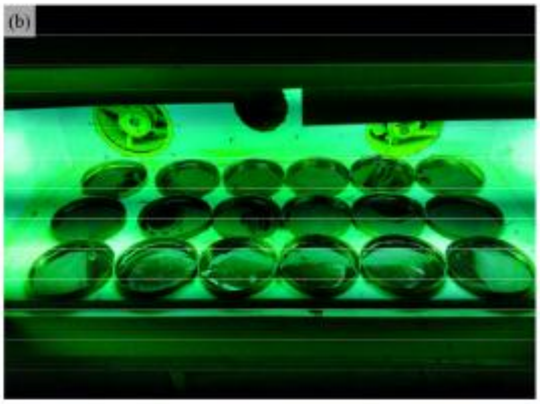

Figure (3): Samples in UV exposure test

4 RESULTS AND DISCUSSION

The gradation for rubber and aggregate is concluded in the results. Also, the qualification test is executed.

4.1 Asphalt mixture and rubber material designed gradation

Based on the gradations of coarse, fine aggregate and mineral filler, the asphalt mixture and rubber- designed gradation and the corresponding specification limits of (4-c) gradation specified by *Egyptian code (2008)* are shown in Tables 4 and 5.

Table (4): Investigated Dense Mix Gradation.

Sieve size		% passing by weight	
inch	mm	Mix designed gradation	Standard gradation (4-c)
1″	25	100	100
3/4 ″	19	93.2	80-100
1/2 ″	12.5	75.3	---
3/8 ″	9.5	65.2	60-80
No.4	4.75	52.6	48-65
No.8	2.36	37.1	35-50
No.16	1.18	25.9	---
No.30	0.6	20.1	19-30
No.50	0.3	16.1	13-23
No.100	0.15	11.1	7-15
No.200	0.075	7.2	3-8

Table (5): The grain size distribution of rubber material

Sieve size		passing by weight
inch	mm	%
1″	25	100
3/4 ″	19	100
1/2 ″	12.5	100
3/8 ″	9.5	100
No.4	4.75	100
No.8	2.36	86.5
No.16	1.18	53.5
No.30	0.6	47.5
No.50	0.3	15
No.100	0.15	2.5
No.200	0.075	0.5

4.2 Qualification tests of aggregates

Bulk specific gravity, saturated surface-dry specific gravity, apparent specific gravity, water absorption, and Los Anglos qualification tests were conducted according to the Egyptian and AASHTO specifications. It gives a satisfied result for water absorption, Los Angeles abrasion, and stripping percentages, as shown in Table 6.

Table (6): Qualification Tests of Aggregates

Test	AASHTO Designation No.	Result	Specification limits,%
Bulk specific gravity (gm/cm3)	T-85	2.64	-
Saturated surface-dry specific gravity (gm/cm3)	T-85	2.67	-
Apparent specific gravity	T-85	2.71	-
Water absorption (%)	T-85	1.04	≤ 5
Los Angeles abrasion;	T-96		
- **After 100 rev. (%)**		4.33	≤ 10
- **After 500 rev. (%)**		22.0	≤ 40
Stripping (%)	T-182	> 95	≥ 95

4.3 Properties of un-modified asphalt mixture using Marshall test

Marshall Test was performed to measure optimum asphalt content (OAC), and the related mix properties, including stability, unit weight, flow, air voids, and voids in mineral aggregate, to study the field performance of the asphalt mixture. The test criterion selected was for a 75-blow Marshall compaction according to *ASTM D1559*

(1978) and *AASHTO T-245* (1986). Marshall Test results and curves are shown in Table (8) and Figure (4).

Table (8): Results of Marshall test calculations for 4% to 7% bitumen

Bitumen amount by weight of 1200 gm	**4%**	**5%**	**6%**	**7%**
Density (unit weight) (gm/cm3)	2.317	2.342	2.389	2.372
Voids in mineral aggregate (%)	15.6	15.4	14.6	16
Voids in specimen (%)	6.8	4.5	1.3	0.8
Stability (ib)	18778.5	1995	1892.5	1707
Flow (inch)	12.45	13.35	13.5	13.85

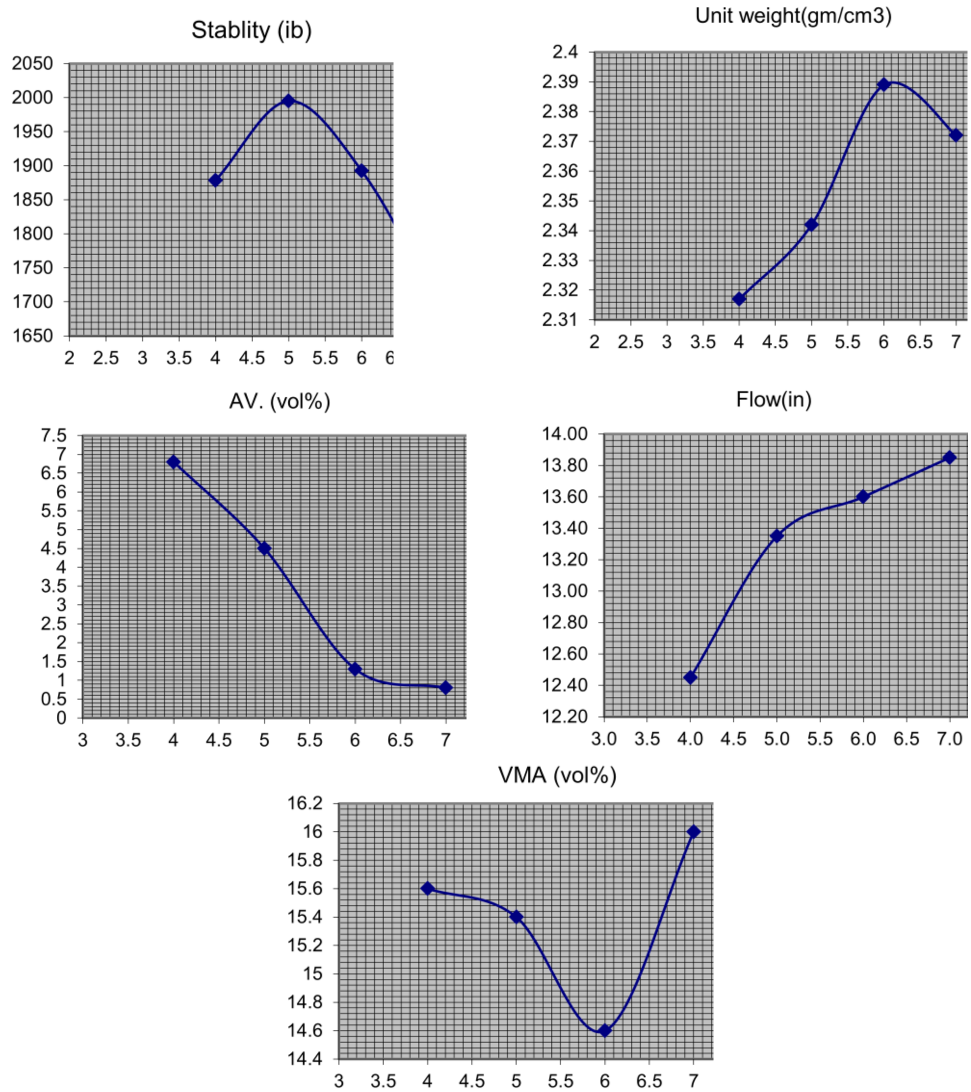

Figure (4): Marshall Test results curves

The results show that the optimum asphalt content (O.A.C) value is 5.4%. The O.A.C and the corresponding Marshall properties for the ordinary base mixture (un-modified mixture) are recorded in Table (9). For type A, stability is 1967 (ib). For Type B, the stability for 5%, 10%, 15 % after adding bitumen are 1840, 1960 and 1996 (ib). The percentage of 10% is the nearest value to other type.

Table (9): O.A.C and Marshall Properties for base mixtures

O.A.C %	Stability (ib)	Flow	Unit weight (gm/cm^3)	A.V %	VMA %
5.43	1970	13.45	2.364	3.1	15

4.4 UV test results

The exposure to UV is executed for several exposure times to compare between two types of mixtures, 1, 2, and 3 months to reach adequate comments on the asphalt's performance over time. Penetration and ductility tests are performed for specimens before and after the addition of rubber material to compare the two types of addition, A and B.

4.4.1Penetration test

Some features reflect the impact of UV, such as the temperature stiffness of the surface layer, which can be estimated by measuring ductility and penetration attenuation rate. All these features change with the time of exposure to radiation (Zadshira M., 2020). Aging causes the low-temperature stiffness of the upper layer of the asphalt mixture to increase, often resulting in temperature shrinkage cracking (Yu H.N., 2019).

UV rays, coupled with the impact of rain and snow, promote road surface deterioration and seriously affect its durability (Zaumanis M.,2015). Consequently, the aging effect of UV radiation on asphalt pavement materials cannot be ignored (Durrieu F., 2007). The calculated values before and after exposure are shown in Table 10. The penetration attenuation rate of UV is defined as the penetration attenuation index, which is calculated by the equation:

$$U_{UV} = \frac{(P_0 - P_{UV}) * 100}{P_0} \qquad (2)$$

Where:

U_{UV} is the penetration attenuation index of UV (for any period of time)

P_0 is the penetration at 25^o C before binder aging

P_{UV} is the penetration at 25^o C after binder aging

Table (10): The Penetration Attenuation Rate %

specimens	Penetration attenuation rate %			
	Before exposure	**UV1M**	**UV2M**	**UV3M**
A	28.21	32.45	50.32	61.87
B	12.78	19.54	24.24	38.12

If the penetration is less than 20, it indicates that the aging limit has been reached and that this cannot be used for asphalt regeneration (Zuo L., 2021). The absolute value of the penetration of UV3M had a more significant impact on the penetration of later aging. UV aging can be restricted by the penetration index. The penetration index and temperature stiffness have a relationship. As the penetration index increases, the temperature stiffness increases (Setyawan A., 2019). For the modified specimen A, the penetrations of all tests were more than B but with little change. For UV2M and UV3M, the penetration rate is stated to increase highly for both. The penetrations are 28.21% and 12.78% for A and B types, respectively, which indicate the high performance of type A against temperature in the natural case. For one month, it decreases, then increases after two and three months.

4.4.2 Ductility test

Strategic Highway Research Program (SHRP) demonstrated that asphalt binder properties significantly impact the low temperatures performance of asphalt mixture (Asphalt institute, 2003). Low-temperature ductility of asphalt was more excellent than that of RTFOT aging. The final determination of the ductility index value of the asphalt should refer to the ductility index value after RTFOT aging of the asphalt in JTG F40-2.

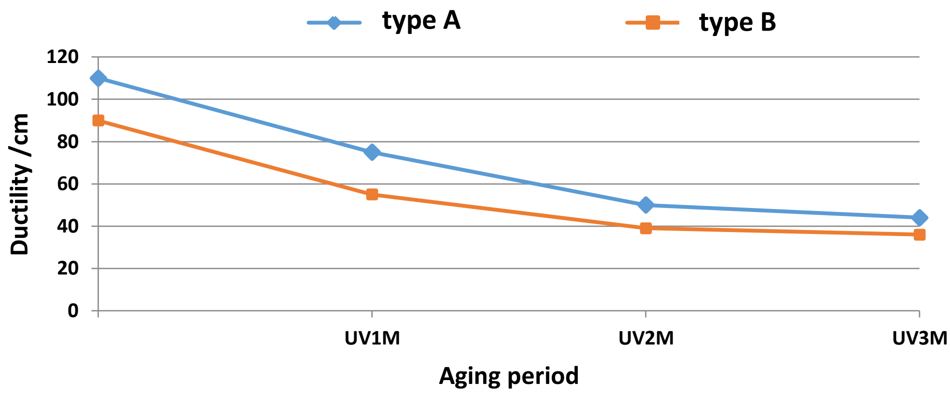

Figure (5): The ductility of binders with different aging periods

The previous figures show that the decrease in the ductility of asphalt showed a slowing trend after exposure for both types, but had high effects on type A. type B has highly sensitivity to UV aging because of low temperature ductility. Type A has high ductility values, with an average of 13% for all cases that mean high stiffness and crack resistance with time (Hernández M., 2015; Zeu et al., 2017). But it can be noticed that after exposure for three months, the ductility decreased and closely to each other but still higher than Type B because of the excessive effect of the radiation on the rheological stiffness properties at any case. Based on this, it can be concluded that, on the one hand, type A is suitable for use in countries with high temperatures because of its high-temperature stiffness, high ductility, and penetration attenuation rates.

5 CONCLUSIONS

Many positive features, particularly those concerning the durability of asphalt–rubber mixtures, are due to the higher binder content in asphalt mixtures. In asphalt mixtures, there are many techniques to add or mix the rubber material with other asphalt components; bitumen and aggregates. It differs by taking it as a percent of the bitumen to make modified bitumen, then adding it to the mixture (type A), or adding it as a part of the aggregate weight (type B). Many studies used type A, and a few used type B. The climate changes with a noticeable increasing of temperatures and radiations in some regions. This study illustrates the aging process for a hot mix asphalt to achieve a comment of the asphalt aging performance for each type of additions and the reason to choose such technique of mix to be appropriate for hottest regions.

The hot mix is prepared with a different adding percentage of rubber materials. The optimum bitumen percentage is estimated using Marshall Test. Asphalt–rubber mixtures with 2% of the whole sample weight are characterized by the following advantages compared to asphalt mixtures with a percent of an aggregate. UV tests have been executed on the two types of modified samples. The examined aging performance indicators are ductility and penetration attenuation. High ductility means high stability, durability, flexibility, thermal cracking, flow, and cohesion. Type A has high ductility values with an average 13% for all cases, which mean high stiffness and cracking resistance with time. The penetration rates are 28.21% and 12.78% for A and B types, which indicate the high performance of type A against temperature in the natural cases. So, Type A is more suitable for use in countries with high temperatures. Here, sustainability claims are made not only by using recycled material but also by checking the sustainable performance. Also, outcomes aid manufacturers in comparing the percent of modifiers for rubberized bitumen to enhance its resistance to UV aging and promote sustainability in construction.

It is worth noting that because this study conducted a single UV aging test, the samples used were not subjected to heat aging treatment. So, it is recommended to be tested with different heat featured in the hottest areas in Egypt to improve the practical side of the weathering effect.

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