Pavement Binder Course Optimization

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Abstract

The main objective of this study is to design the asphalt pavement structure for the Alkut-Mayssan highway in Iraq as a case study by using PCASE application to determine the necessary thickness of CR-modified asphaltic layers. Additionally, Marshall tests were used to investigate the effect of the dry process crumb rubber modifier on the thickness of the binder coarse layer based on various variables, such as the crumb rubber modifier with different content (1, 2, 3, 4, 5)% and sizes (0.3mm, 2.36mm , 4.75mm, and mix gradation). The test results show that while pavement thickness reduced as crumb rubber gradation increases, MR values increase. Additionally, as compared to the control mixture, the addition of 1% of CR in various gradations could decrease the thickness of the asphalt binder layer.

Keywords: Pavement thickness; crumb rubber, dry method; PCASE, MR, Marshall test.

تحسين الطبقة الرابطة للطريق

ابرار عبد الجبار، حسن موسى جواد

الخلاصة

تهدف هذه الدراسة إلى تصميم هيكل الطريق الأسفلتي لطريق الكوت - ميسان في العراق كدراسة حالة باستخدام برنامج PCASE لتحديد السمك المطلوب للطبقات الإسفلتية المعدلة بفتات المطاط، تهدف الدراسة إلى دراسة تأثير إضافة الفتات المطاطي على سمك الطبقة الرابطة باستخدام الطريقة الجافة عن طريق إجراء اختبارات مارشال. تعتمد\ الدراسة على متغيرات مختلفة مثل الفتات المطاطي بنسب مختلفة (١، ٢، ٣، ٤، ٥) % والتدرجات (٠,٣ مم، ٢,٣٦ مم، ٤,٧٥ مم، وتدرج مختلط) باستخدام العملية الجافة من خلال إجراء اختبارات مارشال. تشير نتائج الاختبارات إلى أنه مع زيادة تدرج المطاط المكسر (٠,٣مم،مم ٢,٣٦مم، ٤,٧٥مم، ومختلط)، بزيادة نسب الفتات المطاطي بالخلطات الاسفلتية تزداد قيمة MR وينخفض سمك الطبقات الإسفلتية.، يُظهر إضافة ١٪ من الفتات المطاطي بالتدرجات المختلفة القدرة على تقليل سمك طبقة الرابطة الإسفلتية بالمقارنة مع خليط التقليدي بدون إضافات.

1. Introduction

The most popular form of transportation is surface transit, and pavements are a crucial component of all highways, streets, and parking lots worldwide. The number of paved roads in a nation is sometimes used to measure that nation's growth. Pavements are intended to be sufficiently strong and durable for their design life, just like other engineered constructions. By giving the traffic a smooth surface to move on in a variety of environmental situations, they are expected to function as intended. Pavements must be appropriately planned, constructed. maintained, and managed in order to achieve this (Mallick and El-Korchi, 2013) [1]. Different approaches are used as the theoretical basis for pavement design, and they are based on empirical relationships. Field measurements and observations are used to correlate the in-situ performance of pavements while taking traffic volumes and environmental factors into consideration. To be able to predict how the pavement will behave, it is essential to understand the properties of the soil, the quality of the materials used, and the construction techniques used, up to and including those based on elastic multilayer design. The creation of computer programs like ALIZE, ELSYM5, BISAR, and KENLAYER, among others (Leiva et al., 2011) [2] has helped make this last strategy easier.

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Shafabakhsh et al. (2015) [4] investigation of the effects of asphalt traffic characteristics, subgrade soil type, and base layer thickness. The ideal concrete pavement design can be provided by concrete slab thickness. In the study, 288 specimens were created using the PCASE program to account for the quantity of comparable single axles, the subgrade modulus of the building site for the concrete pavement, and the base layer thickness. The ideal neural network is trained and tested using these samples, and the findings are used to establish the importance of pavement design parameters. According to the method used in this paper to determine the relative significance of each parameter involved in the concrete pavement thickness, the base layer thickness and the quantity of equivalent single axles have the lowest and highest levels of influence, with values of about 21 and 42%, respectively. The outcomes are likewise in line with the structural principles and attributes of concrete pavements. In order to construct flexible-type structure pavements at a military base, Wilches (2020) [5] adopted a process that considered the distinctive features of the typical traffic along the roadways and access areas of these entities on Colombian land. The North American Asphalt Institute's MS-23 Manual, "Thickness Design Asphalt Pavements for Heavy Wheel Loads," the AASHTO method (Version 1993), and the program Pavement-Transportation Computer Assisted Structural Engineering PCASE, developed by the Transportation Systems Center & Engineering Research and Development Ce, were the three design approaches used for modeling the pavement structures. The results showed that under two different subgrade bearing capacity circumstances, it was possible to identify the typical pavement construction sections made up of an asphalt folder and granular foundation.

In order to characterize Iraqi traffic and determine the typical design vehicle, it was first necessary to conduct an inventory of the various traffic vehicles on the country's roads. This allowed for the consideration of the most essential loads in terms of both their size and tire configuration. Following the selection of the design vehicle, the pavement structures were modeled using PCASE software and the AASHTO Method (1993) design method.

2. Object of Study

The purpose of this study is to design the asphalt pavement structure for the Alkut-Mayssan highway as a case study, using the PCASE application to calculate the required thickness of asphaltic layers and the Marshall tests to investigate the impact of the crumb rubber modifier's dry process on the thickness of the binder coarse layer based on various variables.

3. Case Study: Alkut-Mayssan Highway

Alkut is a town in the center of Iraq and is situated around 180 kilometers southeast of Baghdad. The city's eastern entrance is the Alkut-Mayssan highway, which connects it to the Iraqi province of Mayssan. Rebuilding a 10 km portion of the Alkut-Mayssan roadway is essential due to considerable deterioration and a loss in serviceability. This particular section was chosen since it falls within the Alkut municipality's boundaries; any locations outside of this range were not taken into consideration for the rehabilitation project.

Table (1) contains specific information regarding the highway.[11]

Property	**Information**
Entrance information from Maysan Province	It lies in Wassit Province, and it is considered as Al-Kut city
Center line's coordinates	N 576723 E 358049 N 584771 E 3603902
Length of the project	10 km
Number of lanes	3 lanes/direction
Lane width	3.75 m

Figure (1) shows a map of the Alkut-Mayssan roadway, which runs from the Alhakim district in the east towards Al Mutanabbi square, which is closer to the city center. The map shows the highway's path within the designated section, emphasizing how it linked to the city's central from Mayssan Province.

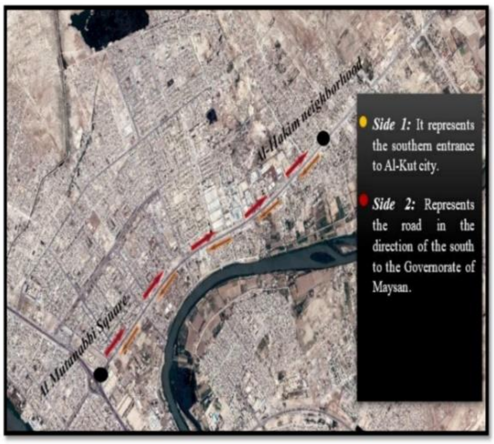

Figure (1): Alkut-Mayssan highway map

4. Experimental work

4.1. Materials

4.1.1. Asphalt Binder

The asphalt binder used in sample preparation for experimental work is AL-Daurah type with penetration grade AC40-50 obtained from the Daurah refinery. This asphalt binder is commonly used in the construction of major roads in Iraq. Table (2) and Figure (2) show the physical properties and tests of the asphalt binder.

Table (2): Physical Properties of Asphalt Binder.

Property	Durah asphalt binder
Penetration	43
Rotational viscosity (c.P)	479.01
Softening point (°C)	51
Ductility (cm)	>100
Flash Point(°C)	>240
Specific Gravity	1.02

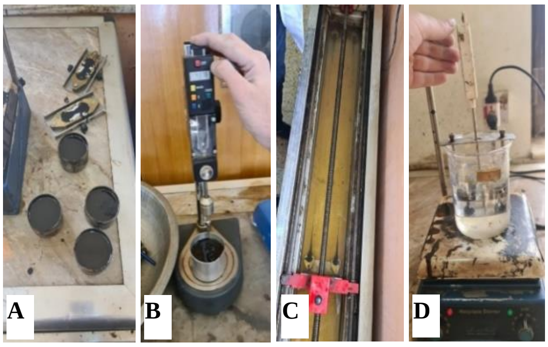

Figure (2): Physical Properties Tests for Asphalt binder, A-preparing the samples, B- penetration test, C-Ductility, D- Softening Point.

4.1.2. Aggregate

The coarse aggregate used in this study was obtained from AL- Kut quarries, which are crushed stone particles. This type of aggregate is commonly used in the construction of asphalt pavements in Iraq's middle and southern regions. As a fine aggregate, natural and crushed sand with a black color is used. As a filler, ordinary Portland cement was used. The aggregate particles were sieved first, then washed and dried in an oven to a constant weight at 110°C, and then recombined in the appropriate proportions to meet the required gradations based on (SCRB, R/9, 2003) binder layer specifications. Table (3) and Figure (3) show the physical properties and gradation of the aggregate used in this study.

Table (3): Physical Properties of the Aggregate.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	2.51	2.67
Apparent Specific Gravity	1.96	2.25
% Water Absorption	1.51	1.74
% Wear (Los Angeles abrasion)	13%	----
Angularity	95%	----

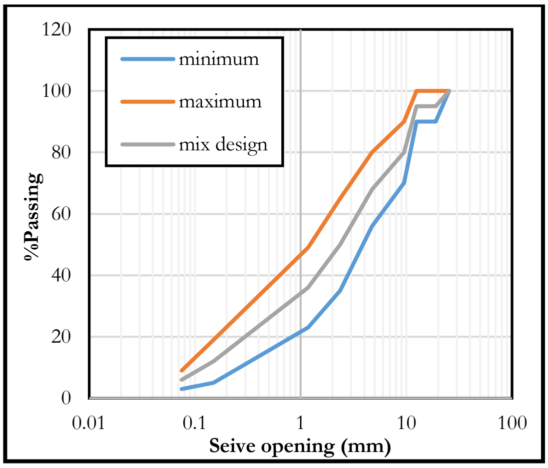

Figure (3): The selected aggregates gradation for a binder layer.

4.1.3. Crumb Rubber

Crumb rubber (CR) is a modifier that is imported from the Al-Kut towers tire factory in the city of Al Diwaniyah. Its component parts range in size from 0.3mm to 4.75mm and are made from used tires. The general appearance of the crumb rubber surface for each size of particle has been determined using scanning electron microscopy (SEM) tests on CR samples with different gradations (4.76, 2.36, and 0.3mm), as shown in Figure (4).

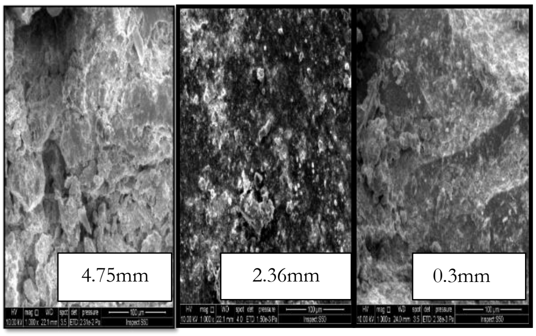

Figure (4): Scanning Electron Microscopy results of crumb rubber (CR) with different sizes at 100 μm.

4.2. Crumb Rubber Modified-Asphalt Mixture Preparation

The dry mixing technique was used to create modified asphalt concrete samples with crumb rubber after the aggregate preparation process was complete and the aggregate was prepared and ready to use in sample preparation. A portion of natural aggregates were modified by using crumb rubber of the same size fraction in their place. In this work, different (CR) percentages and gradations were used.

Before adding the asphalt binder, the aggregates and crumb rubber modifier were mixed in the prescribed amounts. In order to have a suitable mixing process for the asphalt binder mixture, the amount of crumb rubber was combined with the aggregate and asphalt binder at a temperature between (160 °C to 170 °C). For the purpose of conducting tests, modified asphalt binder mixture samples with CR (1%, 2%, 3%, 4%, and 5% by aggregate weight) and gradation (4.76, 2.36, and 0.3mm) were created. According to ASTM D.1559, the asphalt concrete samples were created in Marshall molds with a 101.6mm diameter.

4.3 Laboratory Tests

In order to determine the ideal percentage of crumb rubber to provide the minimum necessary thickness of asphalt layers that provide the overall best performance of asphalt pavements, the Marshall test was used to investigate the impact of using different percentages of crumb rubber on the thickness of asphalt pavement layers.

4.3.1. Marshall Test

Marshall apparatus was used to conduct the test in accordance with ASTM (D-1559) guidelines. Each mixture's Marshall stability and flow were assessed in the lab. Additionally, for each sample control and modified with different CR contents (1, 2, 3, 4 and 5%)

and different particle sizes of CR (0.3, 2.63, 4.75 mm and mix of equal percentages from the three sizes) as well as unmodified mixture samples, density, bulk specific gravity, air voids, and voids in mineral aggregate percent are determined. The standards for the 75-blow Marshall design method were followed in the preparation of all the tested Marshall samples (control and CR modified).

According to the relationship between Marshall stability and resilient modulus of asphaltic mixtures that are found in AASHTO (1993), the following equation can be derived for values exceeding those in the chart:

MR= Marshalll Stability *483 ….[10]

Where, MR: is the Resilient Modulus in (psi) and Marshalll Stability in (kg)

5. The Structural Design

Full-depth asphalt pavements are made by laying down Hot Mix Asphalt (HMA) in one or more layers directly on the subgrade or upgraded subgrade, as shown in Figure (5).

The new flexible pavement will be designed using the (AASHTO, 1993) methodology. The following parameters are necessary when designing surfacing layers with PCASE software:

1- Traffic volume.
2- Index of serviceability
3- Reliability
4- Standard deviation
5- Effect of the environment.

The Alkut-Mayssan highway project's structural design for the layers is based on established designs by the administration. The methodology described in AASHTO, which involves determining layer depth based on the relationship between resilient modulus and Marshall stability, will be followed by an alternative calculation for layer depth using various mixtures in this section.

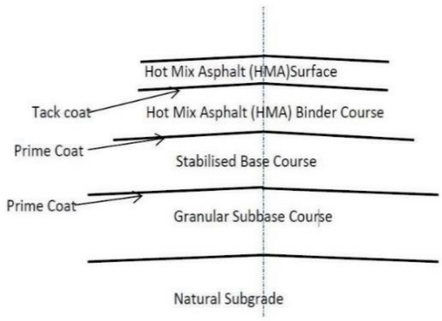

Figure (5): Typical flexible pavement configuration: High Traffic Volume (Congress, I. R., 2001)

5.1. PCASE 2.09 Software

A kind of software called PCASE (Pavement Computer-Aided Structural Engineering) is used for pavement design and analysis. Engineers can use this effective tool to design and assess pavement structures for various kinds of roads and highways. Users of PCASE can enter information about traffic volumes, material characteristics, and environmental conditions to produce precise pavement designs that adhere to predetermined performance standards. Engineers can use the software's advanced features, like sensitivity analysis, optimization, and life-cycle cost analysis, to make knowledgeable choices about the design and upkeep of pavement. All of the benchmarks and evaluation criteria for roads and airports have been compiled by this software into one collection. According to Adolf et al. (2010)[8], PCASE is an essential resource for any engineer engaged in pavement design and analysis.

The "CBR-Design Index Method" and the "Elastic Layered Method" from the PCASE program (Pavement Transportation Computer Assisted Structural Engineering) have been used in the pavement design of MSR Aspen Road.

According to the "AASHTO Guide for Design of Pavement Structures," the PCASE "Elastic Layered Method," which was used in this study, has produced more reliable design results when dealing with the fundamental properties of pavement materials and limiting the vertical and horizontal strains brought on by traffic loadings. Input information needed for this calculation is presented in Table (4).

Table (4): PCASE input data

Input	Type Value
ESAL	30,000,000
ΔPSI	2
Reliability	99
Standard Deviation	0.49
Resilient Modulus (MR)	Different values

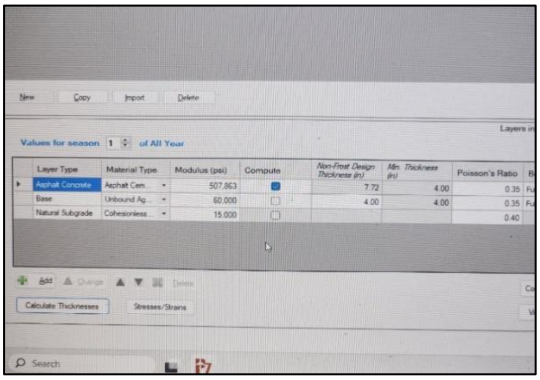

Figure (6): An illustrative image of the PCASE software interface.

6. Results and Discussion

6.1. Resilience Modulus (MR)

The ability of the material to withstand applied loads and distribute stress throughout the pavement layers is typically related to how MR affects pavement thickness. Greater stiffness and resilience are indicated by higher MR values, which may affect the necessary pavement layer thickness.

The material is more resistant to deformation under traffic loads when the MR of CR-modified asphalt mixtures is higher. As a result, it might be possible to thin out the asphalt layers without losing performance standards. Saving money, maximizing the effectiveness of the construction process, and optimizing the pavement design as a whole are all possible advantages.

6.1.1. The Effect of Crumb Rubber Content on Resilience Modulus (MR)

The results of the Marshall stability and Resilience Modulus (MR) tests of control and CR-modified asphalt mixtures with various percentages and gradations are shown in Table (5) and Figures (8) and (8). Asphalt binder should be present at a maximum of 4.6% in both control and CR-modified asphalt mixtures.

According to what is shown in Figure (7), the values of Resilience Modulus (MR) increase as Marshall stability of asphalt mixtures increases, regardless of the content and gradation of CR in the mixtures.

As shown in Figures (8), the dry addition of CR modifier to asphalt mixtures resulted in higher values of Marshall stability when compared to control mixtures as well as higher values of Resilience Modulus (MR) and better resistance to deformation.

The higher Resilience Modulus (MR) values for CR-modified asphalt mixtures were at 1% of CR modifier, regardless of CR gradation and asphalt binder content.

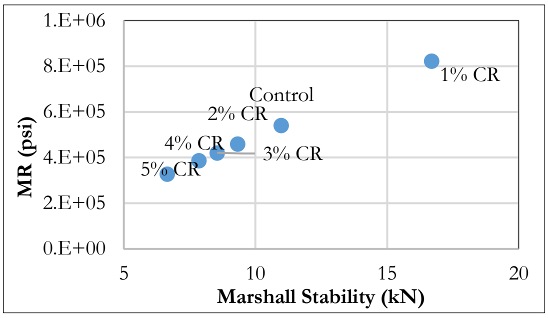

Figure (7): the relationship between Marshall Stability and Resilience Modulus (MR) for control and CR-modified asphalt mixture with 0.3mm gradation.

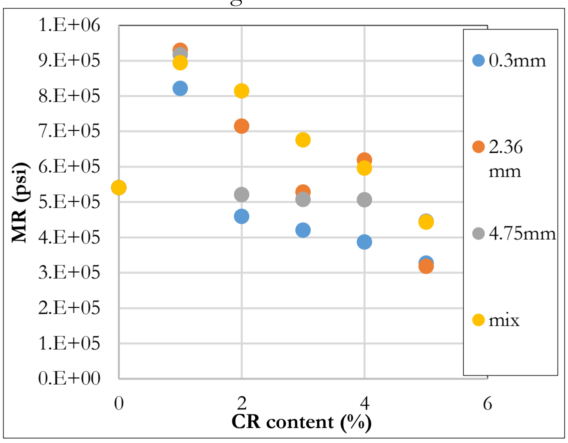

Figure (8): Resilience Modulus (MR) values for control and CR-asphalt mixtures with different gradations and percentages of CR.

Table (5): Marshall Stability and Resilience Modulus (MR) Values for Control and CR-modified Asphalt Mixtures with Different Gradation

Asphalt Mixture Type		Stability (kN)	MR (psi)
% of CR	**CR gradation**		
Control	0	10.985	541060.8
1	0.3	16.69	822057.8
	2.36	18.867	929284.9
	4.75	18.614	916823.5
	mix	18.15	893969.4
2	0.3	9.323	459199.8
	2.36	14.519	715126.2
	4.75	10.577	520965
	mix	16.54	814669.6
3	0.3	8.546	420929
	2.36	10.736	528796.4
	4.75	10.311	507863.3
	mix	15.95	785609.4
4	0.3	7.858	387041.9
	2.36	12.564	618833.7
	4.75	10.282	506434.9
	mix	12.112	596570.6
5	0.3	6.654	327739.5
	2.36	6.465	318430.4
	4.75	9.054	445950.3
	mix	8.997	443142.8

6.1.2. The Effect of Crumb Rubber Gradation on Resilience Modulus (MR)

Table (5) and Figure (9) show that, regardless of the amount of crumb rubber present, the MR values rise as the crumb rubber particle size increases from (0.3, 2.36, 4.75, and mix) in comparison to control asphalt mixtures.

Smaller crumb rubber particles typically improve the mixture's elastic behavior and resilience. They may aid in enhancing deformability and recovery, increasing resistance to fatigue and cracking. On the other hand, larger rubber particles might give the asphalt mixture more toughness and durability.

The higher values of MR were at 2.35mm CR gradation with higher value of Marshall Stability followed by 4.75mm and then mix gradation of CR, according to the results shown in Figure (9).

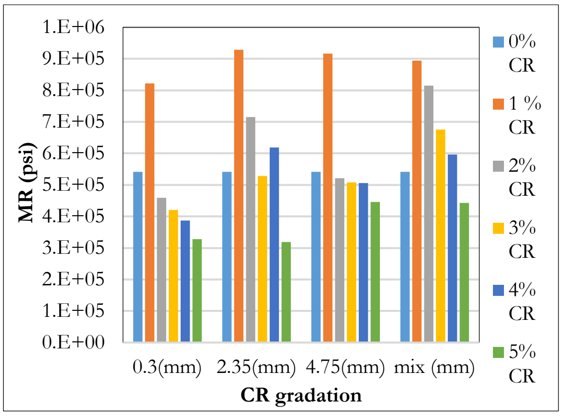

Figure (9): Comparison of Resilience Modulus (MR) between different CR-modified mixtures with different gradations and percentages of CR.

6.1.3. The Effect of Asphalt Binder Content on Resilience Modulus (MR)

Using Marshall tests, a group of three samples of various asphalt mixtures with five percent asphalt binder contents (4.3, 4.6, 4.9, 5.2, and 5.5%), five percent of crumb rubber (1,2,3,4, and 5%), and one gradation (0.3mm) are prepared in order to study the impact of asphalt binder content for CR-modified asphalt mixtures on the Resilience Modulus (MR) values. Table (6) and Figure (10), which show the results of Marshall Stability and MR values, respectively.

Based on the findings in Figure (10), it can be concluded that adding CR to asphalt mixtures generally increases their resilience modulus when compared to control asphalt mixtures, with higher values of MR occurring at 1% of CR.

The findings in Table (6) showed how the values of MR decreased as the amount of asphalt binder increased.

Additionally, Table (6) demonstrated that all asphalt binder percentages, with the exception of (4.6 and 4.9)% of asphalt binder, showed an increase in MR values as crumb rubber (CR) content increased from (1 to 5)%. This is because a material's resilient modulus (MR), such as rubberized asphalt mixtures, can affect the design and effectiveness of pavement thickness. One of the factors taken into account during the design of a pavement is the MR value, which reflects the stiffness and elastic response of the material under cyclic loading.

Table (6): Marshall Stability and Resilience Modulus (MR) Values for Control and CR-modified Asphalt Mixtures with 0.3mm Gradation and Different Asphalt Binder Contents.

Asphalt Binder content (%)	% of CR	Stability (kN)	MR (psi)
4.3	0	9.555	470626.851
	1	18.841	928004.239
	2	16.311	803390.327
	3	14.937	735714.629
	4	11.963	589231.714
	5	10.585	521358.998
4.6	0	10.985	541060.802
	1	16.69	822057.786
	2	9.323	459199.805
	3	8.546	420929.05
	4	7.858	387041.946
	5	6.654	327739.515
4.9	0	7.28	358572.839
	1	15.873	781816.851
	2	13.699	674737.544
	3	13.6	669861.348
	4	11.842	583271.918
	5	15.126	745023.731
5.2	0	6.955	342565.123
	1	18.752	923620.588
	2	17.939	883576.67
	3	16.884	831613.162
	4	16.186	797233.513
	5	11.789	580661.429
5.5	0	5.843	287794.107
	1	13.654	672521.091
	2	11.094	546429.544
	3	11.943	588246.623
	4	9.145	450432.502
	5	12.272	604451.357

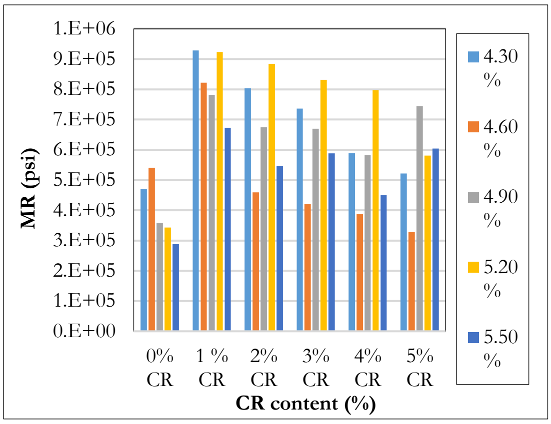

Figure (9) Resilience Modulus (MR)of CR- modified asphalt mixtures with different asphalt binder contents and percent of CR at gradation of 0.3mm.

6.2. Asphalt Pavement Thickness

It is crucial to realize that MR and pavement thickness do not exhibit a linear or obvious correlation. Other factors, such as traffic loading conditions, climate, material properties, and the particular design methodology employed, have a significant impact on the ideal pavement thickness as well.

The design of a pavement structure necessitates a thorough analysis that considers a variety of performance factors and factors other than just the resilient modulus, which is another crucial point to keep in mind. Other aspects like the amount of traffic, the climate, the anticipated lifespan, and budgetary restrictions are also taken into account when designing a pavement.

6.2.1 The Effect of Crumb Rubber Content on Pavement Thickness

The relationship between the resilient modulus (MR) and pavement thickness in rubberized asphalt can be complex and is influenced by various factors. While MR primarily characterizes the stiffness and elastic response of the material, pavement thickness affects several aspects of the pavement structure, including its overall strength, load-carrying capacity, and deformation characteristics.

The thickness of binder layer by using PCASE software for control and CR-modified asphalt mixture based on MR values are presented in Table (7) and Figures (11) and (12).

Depend on the results in Table (7) and Figure (10), regardless the CR gradation, as the CR modifier content increase from (1% to 5%), the thickness of asphalt pavement layers increased comparing to control asphalt mixture.

Based on the results in Figure (4), the optimum percent of CR modifier that provide the minimum asphalt pavement layers' thickness at different gradation is 1% as shown in Figure (10). By increasing the content of CR more than 1%, the high elasticity of rubber particles caused the asphalt mixture to become too flexible. A good asphalt mixture should have a good balance between the strength and flexibility. Too flexible asphalt mixtures become instability under loading conditions (Hassan et al., 2019)[9].

In summary, while higher resilient modulus values lead to decrease in pavement thickness generally as shown in Table (7), it is important to consider other factors and perform appropriate testing to fully understand the relationship between MR and pavement thickness in rubberized asphalt.

Table (7): The Thickness of binder Layers for Different CR-modified asphalt Mixtures with different gradation and percentages.

Asphalt Mixture Type		MR (psi)	Thickness (in)
% of CR	**CR gradation**		
Control	0	541060.8	7.66
1	0.3	822057.8	6.5
	2.36	929284.9	6.22
	4.75	916823.5	6.25
	mix	893969.4	6.3
2	0.3	459199.8	8
	2.36	715126.2	6.83
	4.75	520965.0	7.65
	mix	814669.6	6.52
3	0.3	420929.0	8.26
	2.36	528796.4	7.61
	4.75	507863.3	7.72
	mix	785609.4	6.6
4	0.3	387041.9	8.52
	2.36	618833.7	7.19
	4.75	506434.9	7.73
	mix	596570.6	7.29
5	0.3	327739.5	9.02
	2.36	318430.4	9.11
	4.75	445950.3	8.09
	mix	443142.8	8.1

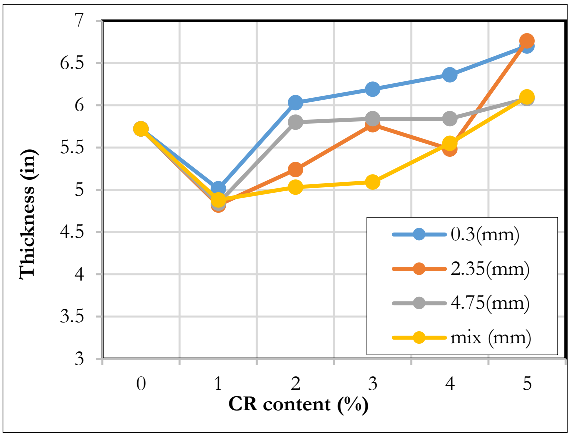

Figure (11): The binder layer thickness (in) for CR-asphalt mixtures with different gradations and percentages of CR.

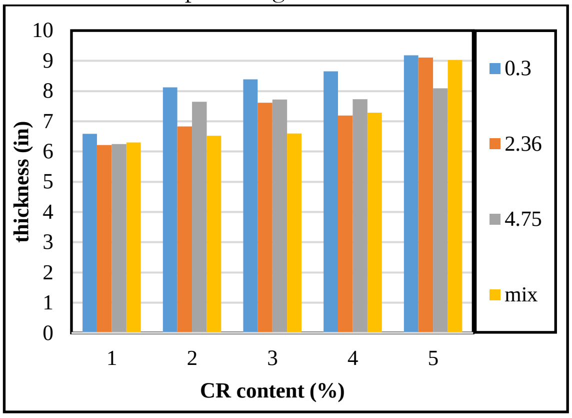

Figure (12): The binder layer thickness (in) for CR-asphalt mixtures with different gradations and percentages of CR

6.2.2 The Effect of Crumb Rubber Gradation on Pavement Thickness

It can be also observed from Table (8) and Figures (13) and (14) that, the gradation of CR has great effect on the thickness of asphalt pavement layers.

It can be seen in the Figure (13), as the crumb rubber (CR) particle size increase from (0.3, 2.36, 4.75, and mix), the MR values increase and thus the binder layer thickness decreases as well.

In general, smaller crumb rubber particles tend to enhance the elastic behavior and resilience of the mixture. They can contribute to improved deformability and recovery, resulting in enhanced resistance to cracking and fatigue. Larger rubber particles, on the other hand, may provide additional toughness and durability to the asphalt mixture. Based on the results that presented in Figure (14), the minimum thickness of binder layer was at 2.35mm CR gradation will higher value of MR followed by 4.75mm and then mix gradation of CR.

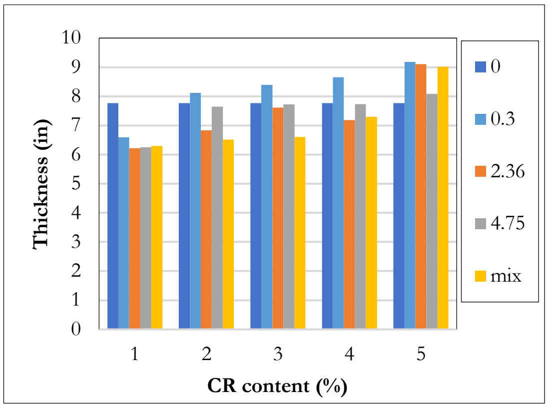

Figure (13): Comparison of binder layer thickness between different CR-modified mixtures with different gradations and percentages of CR.

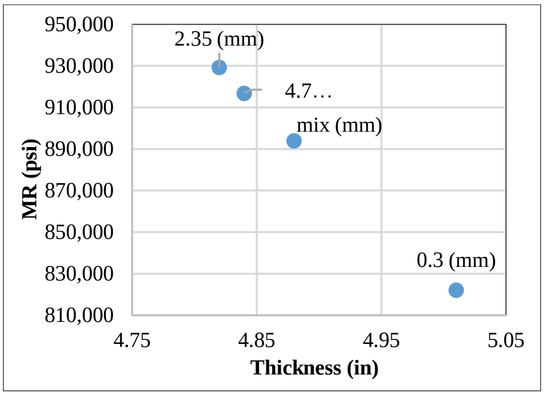

Figure (14): The relationship between binder layer thickness (in) and MR (psi) for CR-asphalt mixtures with different gradations and 1% of CR.

6.2.3 The Effect of Asphalt Binder Content on Pavement Thickness

To study the effect of asphalt binder content for CR-modified asphalt mixtures on the thickness of pavement layers, a group of three samples of different asphalt mixtures (control and CR-modified) with different asphalt binder and crumb rubber contents and one gradation are prepared and tested and the thickness of pavement layers calculated by using PCASE software. The thickness of pavement layers for different content of asphalt binder are presented in Table (8) and Figure (15).

Based on the results presented in Table (8) and Figure (15), in general, the thickness of pavement layers increases with increase the asphalt binder content (control and CR-modified asphalt binder and the addition of crumb rubber modifier has the same effect on different percentages of asphalt binders. Generally, and regardless of the percent of asphalt binder, using any percent of crumb rubber will increase the Marshall stability and then the reliance modulus (MR) causing a reduction in pavement thickness layers compared with control asphalt mixtures. The addition of 1% of CR caused the highest increment ratio in reliance modulus (MR) and a minimum values of pavement thickness as shown in Table (8).

Table (8): The Thickness of Asphaltic Layers for CR-Modified Mixtures with 0.3mm Gradation and Different Asphalt Binder Content.

Asphalt Binder content (%)	% of CR	MR (psi)	Thickness (in)
4.3	0	470626.851	7.09
	1	928004.239	6.54
	2	803390.327	6.89
	3	735714.629	7.11
	4	589231.714	7.71
	5	521358.998	7.76
4.6	0	541060.802	7.77
	1	822057.786	6.59
	2	459199.805	8.12
	3	420929.05	8.39
	4	387041.946	8.65
	5	327739.515	9.18
4.9	0	358572.839	8.21
	1	781816.851	6.24
	2	674737.544	6.57
	3	669861.348	6.59
	4	583271.918	6.92
	5	745023.731	6.35
5.2	0	342565.123	8.24
	1	923620.588	5.81
	2	883576.67	5.9
	3	831613.162	6.03
	4	797233.513	6.12
	5	580661.429	6.85
5.5	0	287794.107	8.24
	1	672521.091	6.13
	2	546429.544	6.4
	3	588246.623	6.59
	4	450432.502	7
	5	604451.357	6.37

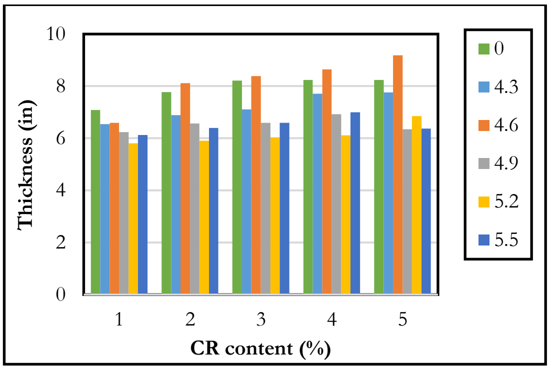

Figure (15): the binder layer thickness of CR-modified asphalt mixtures with different asphalt binder contents and percent of CR at gradation of 0.3mm.

7. Conclusions

Depending on the results of experimental tests and PCASE software in this study, the following conclusions have been drawn:

1-Based on the results of PCASE program that utilized to calculate the resilient modulus based on the Marshall stability, the resilient modulus (MR) of rubberized asphalt mixtures, can have an impact on the design and performance of pavement thickness.

2- Higher MR values indicate greater stiffness and resilience, which can influence the required thickness of the pavement layers.

3- The MR values of rubberized asphalt mixtures are higher than the control mixtures. Increasing the gradation and percent of CR in asphalt mixtures, increased the values of MR.

4- It can have concluded that, at different asphalt binder percentages, as the crumb rubber content increase (1 to 5) %, the MR values increase as well expect in asphalt binder percentage of (4.6 and 4.9) %, the MR values decreases as the crumb rubber content increases from (1 to 5) %.

5-As crumb rubber size increase (0.3,2.36,4.75, and mix), the MR values increase and the pavement thickness decreases as well.

6- The results of PCASE program showed that, regardless of CR gradation, the addition of 1% of CR to asphalt mixtures that used in pavement construction will reduce the thickness of pavement layers comparing to control asphalt mixtures.

7. For the asphalt mixture containing the optimal binder content, it was found that the addition of 1% crumb rubber would increase its stability value, consequently enhancing its MR value and thus reducing the thickness of the bond layer. The best results were obtained when incorporating rubber with a particle size of 2.36 mm, followed by the 4.75 mm gradation, and then the mix and finally with a 0.3 mm size. For the remaining rubber percentages of 2%, 3%, 4%, and 5%, it was found that the 2.36 mm gradation resulted in the thinnest binder layer, followed by the 4.75 mm gradation, and then the 0.3 mm gradation.

8.Acknowledgments

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