The Impact of Crumb-Rubber on the Mechanical Characteristics of Modified Asphalt Mixture

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Abstract. By following up on the effect of rubber, which has recently been widely used as a direct additive to the asphalt binder or to the concrete mix as a percentage of the weight of the aggregate. The success of the effect of this type of admixture on improving the modified asphalt binder in addition to the modified concrete mix has been investigated. As it was noted the importance of following the asphalt properties due to the increasing use of crumb rubber modifiers in asphalt mixtures, there is a more position to check their rheological and physical properties comprehensively. In general, the performance of the asphalt rubber binder is affected by the rubber crumb content and mixing conditions. This research used 40/50 asphalt grade and Crumb Rubber additives with contents (5, 10, 15, and 20%). The main objectives of this study were to investigate the physical and rheological properties of rubber-modified asphalt binder and mixture. These purposes were achieved by testing HMA samples using the Marshall test approach to determine (Marshall stability and flow and void properties) and measuring the retained Marshall stability and DSR and Viscosity test. Sample testing showed that when recycled rubber was used as modifiers for asphalt mixes, the mixture became more stable, had a higher bulk specific gravity, and had less flow value and air voids. This infers that using recycled rubber can enhance the rutting resistance of bituminous mix.

Keywords: Crumb rubber; physical and rheological properties; DSR test; viscosity test.

1. INTRODUCTION

Due to the great importance that basic requirements play such as environmental factors, traffic flow and asphalt mixture materials, it has become necessary for road construction engineers to take into account the basic user requirements for safety as well as economy [1-6]. Installing the aggregates firmly and acting as a waterproofing agent is the main role of the asphalt binder within the asphalt mixture, so the need was felt to study its impact and loss of strength with changes over time in terms of its properties and exposure to some distress such as failure of fatigue, which in turn leads to cracking of the pavement [2]. The properties of the asphalt binder (bitumen) always play a major role in the asphalt mixture, especially that it leads to cracking and cracking resulting from fatigue, which in turn leads to permanent failure in the pavement surface [1].

The fact that the asphalt binder has this important role, as mentioned, and although the dynamic properties and durability of traditional asphalt are limited in resisting pavement pressures, this made it the responsibility of current asphalt researchers and engineers to search for different types of polymer-modified asphalt such as crumb rubber [3]. The mechanism of adjusting/strengthening the improved asphalt binder using rubber crumbs can be extracted in multiple stages, passing through the binder production mechanism and the mixing method until before paving, which is represented by the mixture production [7]. The rubber-modified asphalt binder, according to the study presented by [8,9], provides a modification of the properties as shown:

- The remarkable increase in the consistency at high temperatures of the asphalt pavement leads to avoiding plastic deformation.
- As an expected result of increasing the elasticity of the rubber-modified asphalt binder, it resulted in a significant decrease in crack deformation and fragment loss at low temperatures,
- Increased adhesion ability between bitumen and aggregates,
- High thermal stability, remarkable homogeneity, and aging resistance are among the most important behaviors of modified rubber crumbs, which in turn work to limit the solidification and initial aging of binders during mixing and construction.

Through previous studies of incorporating rubber powder into asphalt cement, the rubber crumb will degrade, and its effectiveness will decrease in prolonged storage at elevated temperatures [2]. Particle dispersion, molecular level dissolution, and physical interaction of rubber with asphalt are the main factors for improving the engineering properties of asphalt rubber (AR). According to Jensen and Abdel-Rahman [10], the important stages of the interaction of rubber with asphalt rubber material were represented by: (1) an early stage that occurs directly when mixing rubber crumbs with bitumen; (2) a later stage of intermediate storage, Where the binder is kept for a few hours at high temperatures, before the process of mixing it with the aggregate; (3) An extended stage (storage) represented by storing the mix of bitumen and rubber crumb for long and varying periods before mixing with the aggregate. The application of nuclear magnetic resonance imaging to asphalt binder material prepared with rubber chips was carried out by [11]. Applying this technique helped to investigate the different interactions between rubber crumbs and asphalt, where swelling by asphalt particles, the possibility of dissolution of rubber components in asphalt, and cracking and cracking in rubber were observed. The observed swelling of the rubber particles, which in turn depends on the asphalt particles, resulted from the study presented by [12].

Also note the most important factors that play an important role in the properties of the modified asphalt binder that are represented by the digestion process of asphalt and rubber mixtures are the rubber content, rubber gradations, binder viscosity, binder source, and mixing conditions of time and temperature. According to laboratory binder tests [13-15], it was observed that the content of rubber crumbs plays a significant role in significantly affecting the performance and rheological properties of modified asphalt binders. It can enhance the performance properties of asphalt pavement resistance against deformation during construction and road services. The modified asphalt binder's properties improved when the rubber crumbs' content was increased from 4% to 20%. This phenomenon can be explained as a result of the absorption of a lighter part of the bitumen oil by the rubber particles, which increases the rubber particles during swelling during the mixing process. The increase in the viscosity values outside the limits of the specification SHRP (3 Pa) is indicated by the increase in the rubber content, which ranges between 16% and 20%, which made these percentages unacceptable for field construction during the construction of the asphalt pavement mixture. As for low temperatures, the ongoing research showed that the asphalt binder, which contains 18-22% of rubber, gives little change in the tensile and fracture performance of bitumen when compared with the addition ratios between 6 and 9% depending on the weight of the bitumen [13, 14]. A study by Khaled [18,21] found that the high content of the binder led to a significant improvement in the fatigue life of the bituminous mixture modified with rubber crumbs, as it showed good resistance to cracking and cracking. It was found that the effect of the factors is according to the sequence illustrated, the content of rubber crumbs, the type of rubber fracture, and particle size [19-21].

Roads face several problems, including but not limited to the increasing traffic volumes and the significant variation in temperature during the days of the year, which prompted many researchers to seek additives that could work as improvers for the mechanical and rheological properties of the asphalt binder, in addition to improving the behavior of asphalt mixtures. This paper is part of a series of research to predict the behavior of crumb rubber-improved asphalt binder mixture. The main objective of this research is to demonstrate the effect of adding crumb rubber extracted from vehicle tires on the rheological properties of the modified binder and the mechanical ones of the hot asphalt mix, where the optimal proportions of the crumb rubber additive were recommended.

2. RESEARCH METHODOLOGY

2.1 Asphalt Binders

In this scientific research, one type of asphalt binder was used, represented by a degree of penetration (40-50), where the asphalt extracted from the Dora refinery is one of the most common and used types in flexible paving in Iraq. Table 1 displays laboratory test results for the asphalt binder.

Table 1: Characteristics of the used asphalt base binder.

Test Name	Standard used	Test Result
Penetration @ 25℃	ASTM D5	47
Softening point (℃)	ASTM D36	50
Flashpoint (℃)	ASTM D92	330
Ductility, Cm	ASTM D113	120
Bulk specific gravity	ASTM D70	1.034
Rotational Viscosity at 135℃ (Pa.s)	ASTM D4402	0.431
Rotational Viscosity at 165℃ (Pa.s)	ASTM D4402	0.136

2.2 Tire Crumb Rubber

Due to the widespread of used and discarded tires and because this type of material (crumb rubber) is known for its good properties, it was used as an improved material for the asphalt binder. The type used in the study was distinguished by high quality (40 mesh), as it was manufactured from used and discarded tires. The material is proven to comply with the Restriction of Hazardous Substances (ROHS) regulations. Modified T-MESH 40 is free from external contaminants and has excellent properties. Figure 1 represents the rubber crumb used in this study, while Tables 2 and 3 represent the recycled rubber's physical properties and chemical composition (T-MESH 40) [22].

In order to reach the stated goals of this study, asbestos cement with a penetration degree of 40-50, which is usually used in Iraq, was used to make samples of rubber-modified asphalt crumbs. The dried rubber crumbs at a temperature of 60 degrees Celsius and passing through sieve No. 50 were mixed with the asphalt binder using a high-shear mixing mechanism at a shear rate of 1000 revolutions per minute for a full hour to ensure a homogeneous distribution of the rubber crumbs and reach the required density [22]. The mixing process was carried out at 160-170 degrees Celsius, and then the mixtures were tested after being placed in tightly closed metal containers in preparation for rheological tests.

Table 2: Physical properties of the recycled tire crumb rubber.

Test	Standard	Result
Passing %	ASTM D 5644	> 90
Heat Loss %	ASTM D 1509	< 1
Metal Content %	ASTM D 5603	≤ 0.1
Fiber Content %	ASTM D 5603	≤ 0.3

Table 3: The chemical constitution of the recycled tire crumb rubber.

Test Name	JIS K 6350	10±5
Ash Content (%)	TGA	5±3
Carbon Black content (%)	TGA	32±5
Rubber Hydrocarbon content (%)	TGA	52±8

Figure 1: Tire crumb rubber used.

2.3 Aggregate

In this research, Al-Nibaee aggregate of both coarse and fine types extracted from northern Baghdad was used. Table 4 shows the physical properties of al-Nubaie aggregate. The aggregates used in this research were treated in coarse and fine types according to the Iraqi specifications for hot mixing, the surface layer [23], where the gradation was confirmed after washing and drying the aggregate to ensure it was free of impurities. One nominal maximum size (12.5 mm) and one pooling gradient were chosen to prepare the HMA samples. In addition, the study adopted the average limit of the Iraqi specifications for dense graded aggregate. To obtain the required proportions for the fine materials, Portland cement from Al-Taji Cement Factory was used with a specific gravity (3.4 g/cm^3) as measured by volume.

Table 4: Physical Properties of Al-Nibaee Aggregate.

Property	Fine aggregate		Coarse aggregate	
	ASTM Specification	Results	ASTM Specification	Results
Wearing resistance (Los Angeles Abrasion)		……	C131	23.1
Bulk Specific Gravity	C128	2.63	C127	2.647
Apparent Specific Gravity	C128	2.668	C127	2.653
Water Absorption (%)	C128	0.66	C127	0.57

2.4 The Conventional Testing

The asphalt binder without the addition of rubber, and when added according to the required proportions, was subjected to traditional tests such as softening point tests, and penetration serially, according to specifications and international limits.

2.5 The Rheological Test

The rheological and operational properties of the modified asphalt binder were studied using a dynamic shear rheometer (DSR) and rotary viscometer (RV). Composite shear modulus (G*), phase angle (δ), and rotational Viscosity were evaluated. The tests represented by the dynamic sheer scale (DSR) and rotational Viscosity (RV) were the way to reach the goals of the study.

2.6 Mix Design

Marshall Design was used to obtain the optimal asphalt ratios to comply with the pulverization conditions and according to ASTM: D6926-2010. Asphalt binder ratios (4, 4.5, 5, 5.5, and 6.0%) were used to find the optimal ratio, and then the samples were prepared by adding rubber crumbs to these ratios at a rate of three samples for each ratio.

3. RESULTS AND DISCUSSION

3.1 Penetration and Softening Point Tests

The physical properties of the asphalt binder, represented by a permeability of 40-50, are confirmed in Table 5 in addition to the rubber-modified bitumen. At the same time, Figure 2 shows the rate of decrease in the penetration values for each of the percentages of the additives used in the study. The apparent ability of crumb rubber to modify the properties of the modified asphalt, such as hardness and tensile strength, was evident in the behavior of the modified asphalt binders. The decrease in permeability and increase in Softening point [22], as shown in Figure 3, was the extracted behavior of the effect of crumb rubber on asphalt. The penetration values decrease with the increase of the rubber crumb in the mixture, indicating that the asphalt cement has become more solid and stable [22, 24-28, and 30].

Table 5: Physical attributes of crumb rubber modified asphalt cement.

Test	Unit	Crumb Rubber (CR)%				
		MB-CR0	**MB-CR5**	**MB-CR10**	**MB-CR15**	**MB-CR20**
Penetration (25℃, 100g, 5s), ASTM D5 (1/10mm)	1/10mm	47	43	39	35	13
Brookfield Viscosity @ 135℃, (ASTM D4402)	(Pa.s)	0.6538	0.8913	1.0981	1.3251	1.6187
Brookfield Viscosity @ 165℃, (ASTM D4402)	(Pa.s)	0.2099	0.3124	0.3505	0.3713	0.3992
Ring and Ball Softening Point (ASTM D36)	(°C)	50	54	60	65	69
Flashpoint (cleave land open cup), (ASTM D92)	(°C)	331.5	361.0	387.5	399.5	410.5
*After Rolling Thin Film Oven Test						
Penetration (25°C, 100g, 5s), (ASTM D5)	1/10 mm	32.5	28.5	22.5	19.7	17.5
Loss on weight (163˚C, 50gm, 5h), (%)		0.3	0.278	0.267	0.260	0.24
Softening Point (ring & ball), (ASTM D36)	(°C)	54.5	57.6	63.1	67.2	69.8

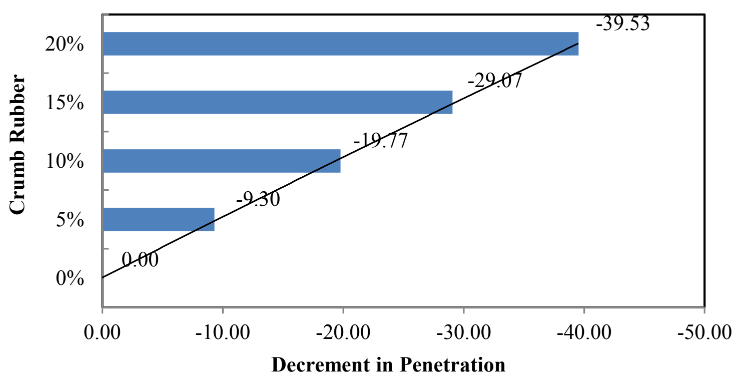

Figure 2: The effect of crumb rubber content on the decrement rate in the penetration values.

The increase in the softening point values and its increased consistency were adopted as evidence that the additive is homogenous in the asphalt mixture, as reported by [22] and shown in Figure 3.

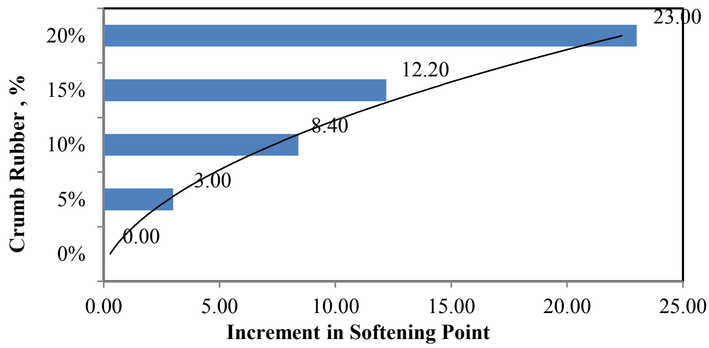

Figure 3: Increment rate in the bitumen's softening point as a result of an increase in crumb rubber content.

3.2 Viscosity Testing

Asphalt viscosity is used to determine the flow characteristics of an asphalt binder to provide some assurance that it can be pumped and cured in a hot-mix facility [22, 28]. 135 and 165°C, respectively, shown in Figures 4 and 5, were used for calculating the mixing and tempering temperatures. Furthermore, increasing the percentage of rubber gives a higher viscosity [28]. Note also that the relationship between Viscosity and the percentage of rubber tires is non-linear, as shown in Figures 4 and 5 for its dependence and effect on the relative increase by applying temperature [29].

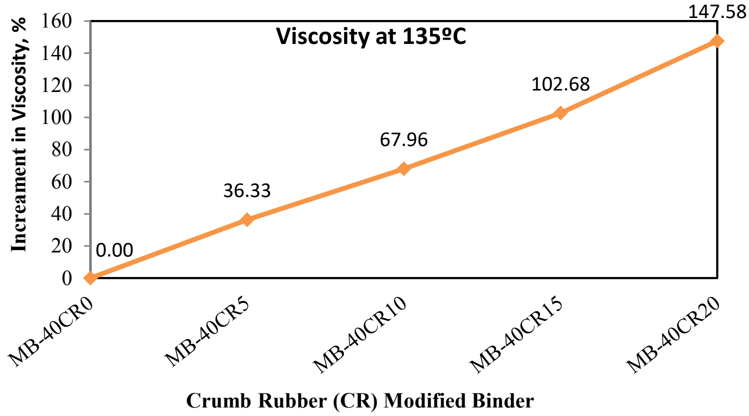

Figure 4: Increment in viscosity percent for CR modified binder (@135˚C).

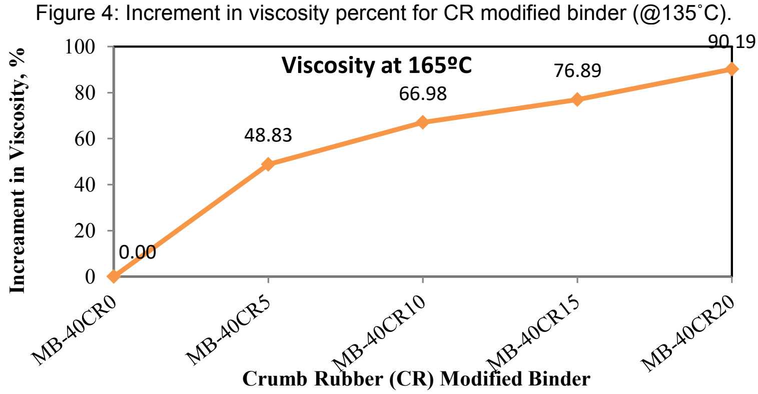

Figure 5: Increment in viscosity percent for EVA modified binder (@ 165˚ C).

The resulting data indicate that the increase in blend stiffness was due to the rise in CR percent. This change was represented by an increase in softening point, Viscosity, and a decrease in penetration as the percent of modification increased. This phenomenon is because as the percent of modification increases, most of the oil in asphalt (molten asphalt) oxides due absorbed by the CR. The magnitude and extent of these changes do, however, vary as a function of the modification percent and aging time duration. The decrease in penetration and increase in softening point indicate an increased hardness or stiffness and show an improvement in the temperature susceptibility of the blends. The modification and aging significantly affected the performance of the asphalt binder [26, 30, and 31]. Mixing and compaction temperatures were selected corresponding to binder viscosity values of 0.17±0.02 Pa.s and 0.28±0.03Pa.s, respectively. Thus, the mixing and compaction temperatures are shown in Table 6 and Figure 6 below. The clear increase in the mixing and compaction temperatures of asphalt mixtures with an increase in the proportion of rubber residues confirmed what was obtained from the traditional tests and the viscosity test that was previously proven.

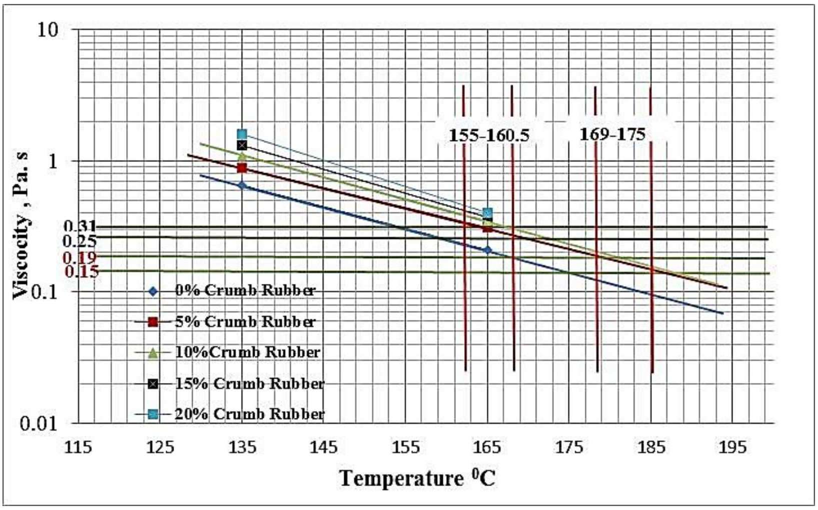

Figure 6: Mixing and compaction temperatures for modified asphalt binder.

Table 6: Mixing and compaction temperatures for Crumb Rubber CR modified binder.

Asphalt Type	Mixing temperature (°C)	Average Mixing Temperature (°C)	Compaction Temperature (°C)	Average Compaction Temperature (°C)
MB-40CR0	169.0-175.0	172.00	155.0-160.5	157.50
MB-40CR5	180.0-186.0	183.00	165.0-170.0	167.50
MB-40CR10	181.0-186.5	183.75	167.0-172.5	169.75
MB-40CR15	182.0-187.0	184.50	169.0-173.5	171.25
MB-40CR20	182.5-188.0	185.25	171.0-175.0	173.00

3.3 The Rheological Performance

The basic rheological properties of the modified asphalt binder were measured using crumb rubber and according to the ratios proven by the study in terms of complex modulus (G*), phase angle (δ), temperature sweep test on the modified asphalt using dynamic shear gauges (DSR). Figure 7 shows the results of the DSR test at predetermined temperatures and increments of 6 °C. To ensure that asphalt cement is flexible enough to resist permanent deformation at high service temperatures, a minimum of 1,000 Pa is recommended for the modulus of fragmentation. It was observed through the results shown in the figure that the fracturing agents for the binders enhanced with rubber crumbs gave the highest strength compared to the basic binder. This improvement is attributed to the positive properties of crumb rubber used in the study compared to the usual binder (40-50), where the figure shows that the failure temperatures of the bituminous binder modified with rubber are higher than those of the basic asphalt cement. Thus, the primary linker's high performance (PG) score is improved. This means modified asphalt can withstand higher temperatures with greater resistance to permanent deformation.

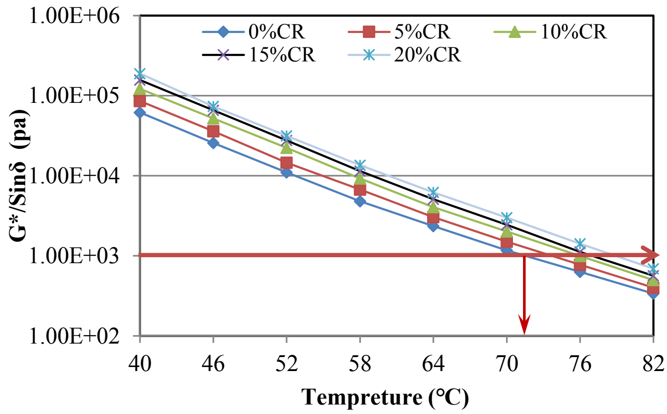

Figure 7: Temperature sweep testing for crumb rubber-modified 40–50 asphalt cement.

3.4 Optimum Asphalt Content for Original Asphalt Mixture

Optimum asphalt content was calculated as per Asphalt Institute Method by taking the average asphalt content corresponding to 4 percent air voids, maximum stability, and maximum bulk density and checking for other parameters. The air voids in the design were kept at 4% per the specification requirements. Figure 8 determines three values respectively for control asphalt 80-100.

a) Bitumen content at the highest stability = 5%.

b) Bitumen content at the highest value of bulk density $(\%\mathrm{mb})_{\mathrm{Bulk\ Density}}$ = 5.4%.

c) Bitumen content at the median of allowed percentages of air voids (Va = 4.9%) $(\%\mathrm{mb})_{\mathrm{Va}}$ =5.71.

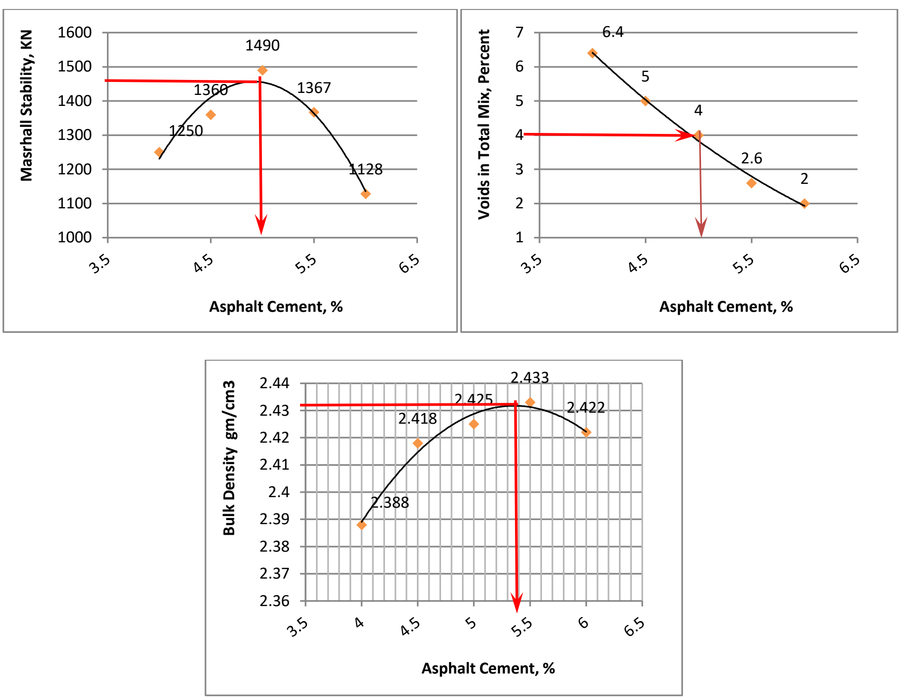

Figure 8: Optimum asphalt content determination (MB-40CR0).

$$AC = \frac{\text{Maximum density} + \text{Maximum stablity} + 4\%\text{Air voids}}{3} \quad (1)$$

AC = 5.1

Figure 9 represents the optimum values for the asphalt and each percentage of the rubber crumb ratio used in the study. The optimal asphalt content decreases after the addition of crumb rubber, and as the crumb content increases, requiring less asphalt, the small difference in the optimal asphalt content of the mixtures is attributed to differences in the specific gravity of course, the medium and fine particle size of the mineral fillers.

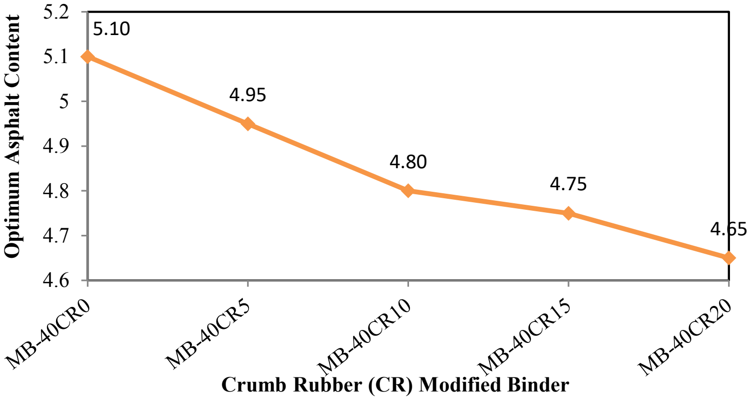

Figure 9: Effect of crumb rubber (CR) content on optimum asphalt content.

5. CONCLUSIONS

In this research, the physical and rheological properties were studied, in addition to the mechanical properties of asphalt mixtures of the type HMA treated with rubber crumbs, as the results showed the following:

- The clear and remarkable improvement in the properties of the asphalt binder modified with rubber crumbs, such as testing the softening point and penetration, in addition to the significant improvement in the rheological properties, such as testing the Viscosity, in addition to the DSR test. This improvement shows the possibility of resisting the modified linker to various conditions of permanent deformation.
- It was discovered that adding rubber crumbs to asphalt concrete increases its stability but reduces its flow. This indicates that using rubber can help asphalt mixtures resist permanent deformation.

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