

## Evaluation the Usage of Local Materials in HMA Surface Layer

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**Abstract.** The importance of roads and all the facilities related to the mobility of people, goods, and vehicles in the world exceed the social and economic significance but play a main role in politics and government decisions. As a result of the increasing population in Iraq and the dramatical growth in heavy vehicles twenty years ago and due to the rising percentage of new construction projects in the country, the need appeared to assess and improve the hot mix asphalt layers used in the construction of flexible pavements. In this research, a hot mix asphalt surface layer was used with a 12.5 mm nominal maximum aggregate size from one aggregate source (Al Nibaie quarry) and one penetration grade type of asphalt binder (40 -50), also in this research work has been added one type of polymers by several percentages namely, Crumb Rubber Modifier (CRM) to enhance the properties of asphalt binder which in turn improves HMA. The evaluation process included the preparation of two types of mixtures (unmodified and modified mixtures) by using the Superpave mix design method and to estimate the ability of mixtures to resist the three main types of failure that may be flexible pavement exposed to, Wheel track test was used to simulate the permanent deformation resistance of mixtures, flexural beam fatigue test to determine the fatigue cracking resistance of mixtures and indirect Tensile Strength test was used to determine the strength to moisture damage for prepared mixtures. Results demonstrated that adding modified waste polymer to the asphalt cement with different percentages significantly improved mechanical and durability properties.

**Keywords:** Asphalt binder; crumb rubber modifier; hot mix asphalt; indirect tensile strength; wheel track test

### 1. INTRODUCTION

Roads, highways, and streets represent the main important part of the infrastructure of any country in the world. Generally, roads can be divided into three main types of construction and materials used: rigid pavement roads, flexible pavement roads, and composite pavement roads [1]. A rigid pavement's surface is usually made of Portland cement concrete such that it acts like a beam over any irregularities in the underlying supporting material. On the other hand, the flexible pavement has a surface of bituminous materials that remain in contact with the underlying material [2]. Finally, A composite pavement is composed of both HMA and PCC. Using PCC as a bottom layer and HMA as a top layer results in an ideal pavement with the most desirable characteristics [1,3]. Flexible pavement (asphalt pavement) is the predominant pavement type in the world. This popularity is due to the availability of materials, especially in a country like Iraq. Compared with rigid pavement, the lower cost in contraction and maintenance and the main reasons for using flexible pavements extensively worldwide is because of its properties that make them unique layers that can resist the traffic volumes and changing climate.

Asphalt pavement is a combination of asphalt binder, aggregates (coarse aggregate and fine aggregate), and mineral fillers and can be classified into three types according to construction types or the mixing temperature. Therefore, asphalt pavements are divided into hot mix, warm mix, and cold mix [4]. The term hot mix asphalt refers to the hot mixtures comprised of different proportions of aggregates and asphalt binder and then mixed together to produce an asphalt mixture that provides a good balance between strength and durability. In contrast, meeting specification requirements [2,5], asphalt binder (Bitumen) is the basic materials in these mixtures because it gives the main characteristics of flexible pavements. In other words, asphalt pavement obtains most of its properties, such as elasticity and rheological characteristics, from the fundamental features of bitumen materials. Although, the percentage of asphalt binder hot mix asphalt is very small and does not exceed 6% in most hot mixes, confirming the significant role of asphalt binder.

Furthermore, according to the aggregate gradation that means the distribution of particle size in the mixtures can be classified the asphalt mixtures into three main groups relatives to aggregate structures dense-graded, open-graded, and gap-graded. The dense-graded mixtures are considered the most common HMA mix type. To define "dense graded," it means that the dense aggregate gradation is used in HMA mixtures, and that is because of the space available between the aggregate particles in this type of mixtures. In the past, dense-graded mixtures were common because they needed lower contents of asphalt binders, keeping the cost low [6,7]. During the past twenty years, the roads in Iraq, especially the main roads that connect the parts and governorates of Iraq to the capital, Baghdad, suffered from many distortions and damages due to the increase in heavy load vehicles, the increase in traffic volume, and the rise in temperatures in general compared to the past decades, and the increasing in population density, which increased the use of raw materials Involved in the construction of housing units and new buildings, and all of what was mentioned above had a bad effect on the flexible pavements in Iraq and increased distresses in them.

One of the most important distresses is permanent deformation (rutting). Especially in countries like Iraq when lying in hot climate areas. Rutting is one of three main distress in flexible pavements (rutting, fatigue cracking, and thermal cracking) [8], and can say rutting is the most famous among them. Rutting is caused by deformation in the underlying aggregate base or subgrade [9]. Asphalt pavement distresses may also result from deficiencies in the hot mix asphalt, where mixtures were not properly designed, produced, or placed. Excessive permanent deformation can occur within one or more asphalt layers by moisture damage, low air voids, poor quality aggregate, and poor construction practices [10].

The second common type of distortion is fatigue (Alligator) Cracking, and fatigue cracking occurs in areas subjected to repeated traffic loadings (wheel paths). It can be a series of interconnected cracks in the early stages of development. Develops into many-sided, sharp-angled pieces, usually less than 0.3 m (1 ft.) on the longest[8]. Alligator cracking is a load-related distress because it is caused by fatigue failure of the asphalt concrete surface and is aggravated by repeated traffic loads [11,12]. This distress will appear initially as longitudinal cracking in the wheel paths for an extended length that will eventually network outward into "alligator" cracks as they mature [13]. This early-onset fatigue cracking can result in total pavement failure well before reaching the intended design life [5, 14]. Fatigue cracking is often related to weakening the base course or subgrade, insufficient pavement thickness, and excessive loading.

To overcome the expected deterioration that facing flexible pavement under excessive traffic loading and environmental condition, therefore much effort has been directed toward developing the properties of asphalt binder because it plays an essential role in the performance of flexible pavement to enhance the mechanical and durability properties of HMA mixtures through modifying the asphalt cement [15,16]. The modification of asphalt binders has been practiced for several years. The increasing demands placed on the performance of asphalt concrete pavements and the development of the PG grading system with the inclusion of grades that have a wide spread between the upper and lower specification temperatures have accelerated the use of modified binders [17]. The modification of asphalt binder to enhance its performance characteristics has occurred in the United States for more than 50 years. Modified asphalt binders are often called "polymer-modified asphalts" or PMAs [18]. Modified asphalt binders may be produced in several ways, including polymer and chemical modification, although polymer modification is most prevalent [5, 14, 15]. Traditionally, incorporating polymer-based materials in bitumen by mechanical mixing or chemical reaction can significantly improve the properties of conventional bitumen [19,20].

The polymers most commonly used are elastomers, plastomers, reclaimed tire rubbers, and to a lesser extent, viscosity modifiers, and reactive polymers [16]. Polymer-modified bitumen (PMBs) are combinations of polymer and asphalt cement [21]. Compared with neat binders, they are often characterized by increased stiffness at high temperatures and improved flexibility at low temperatures, which can provide the corresponding asphalt mixture pavement with enhanced resistance to deformation under traffic load at high temperatures and increased resistance to cracking at low temperatures. Because of their performance, PMBs have been widely used in the construction of road pavements [22]. Historically, two basic types of polymers have been used to modify asphalt cement: plastomers and elastomers. Elastomers are rubber-like at room temperature, whereas plastomers are solid-like at room temperature [17,21]. Elastomeric modifiers are by far the most common in today's market. Elastomeric polymers are typified by their rubber-like properties and their ability to stretch and recover[15]. Concurrently, crumb rubber modified (CRM) is an elastic material. Crumb rubber produced from ground tires is considered differently [15, 23-25].

Recycling waste rubbers as asphalt modifiers has been considered the most potential way from both economic and environmental points[26-30]. Asphalt-Rubber is defined in ASTM as follows: "A blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber content is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling in the rubber particles." [15,31,32]. The use of crumb rubber modified (CRM) asphalt in mixtures falls into three broad categories: dry process defined as any method that mixes crumb rubber modifier with the aggregate before the mixture is charged with asphalt binder at the hot plant. Particle size is typically larger than 10 mesh. The wet process is defined as a method that blends the crumb rubber modifier with the asphalt cement prior to incorporating the binder into the aggregate. Finally, terminal blend technique is a method that blends the crumb rubber modifier with the asphalt binder at the asphalt terminal [4]. The terminal blend process produces CRM asphalt binders in the same general category as the wet process, with the difference being that terminal blend CRM asphalt binders are produced using much smaller CRM particle sizes in a process that facilitates the digestion of the CRM into the asphalt. In this study the effect of waste polymer as CRM on the asphalt binder were significantly evaluated by physical properties and the focus has been around the viscosity test as an indicator of improving the asphalt binder performance. On the other side in terms of mechanical properties of asphalt mixtures, the Wheel track test, flexural beam fatigue test, and indirect Tensile Strength test were used to assess the enhancement of surface mixture as regarding to the role of polymers used in this paper.

## 2. MATERIALS

To accomplish the most realistic simulation of HMA mixtures paved in Iraq. Common local aggregates and asphalt binder grades were selected for fabricating laboratory samples. The materials utilized in this research include asphalt cement, aggregate, and mineral filler. Evaluation of materials characteristics conducted using routine tests and results compared to the requirements of Iraqi Specification SCR B (R/9, 2003). One of the

asphalt cement types used with (40-50) penetration grade was obtained from Al-Daurah refinery located southwest of Baghdad. The physical properties and tests of the used asphalt cement are shown in Table 1.

Table 1: Physical properties of asphalt cement.

Property	ASTM Designation	Test result	SCRB specification
Penetration at 25°C, 100 gm, 5 sec. (0.1 mm) *	D-5	47	(40-50)
Ductility at 25°C, 5 cm/min (cm)*	D-113	>100	>100
Flashpoint (Cleveland open cup) (°C)*	D-92	245	Min.232
Softening point, (°C)*	D-36	52	-----
%Solubility in trichloroethylene*	D-2042	99.2	Min. 99%
Viscosity @ 135°C, Pa. Sec*	D-4402	0.427	-----
Viscosity @ 165°C, Pa. Sec*	D-4402	0.112	-----
Specific gravity at 25°C *	D-70	1.04	-----
<b>Residue from thin-film oven test</b>			
- Retained penetration, % of original*	D-5	69	Min. 55
- Ductility at 25°C, 5 cm/min (cm)*	D-113	68	Min. 25

Crushed quartz aggregates that have been used were obtained from Al-Nibaie quarry north of Baghdad. Laboratory tests were conducted to determine the basic physical aggregates properties. Aggregates routine tests performed at the Karbala University laboratories to evaluate its physical properties. Tables (2) and (3) show the test results of aggregate (coarse and fine) with the limits of Iraqi specification as defined by the SCRBS specifications.

Table 2: Physical properties of coarse aggregates.

Property	ASTM Designation	Coarse Aggregate	SCRB Specification
Bulk Specific Gravity	C127	2.58	-----
Apparent Specific Gravity	C127	2.63	-----
Percent Water Absorption	C127	0.729	-----
Percent Soundness Loss by Sodium Sulfate Solution	C88	2.08	12% Max.
Percent Wear (Loss Angeles Abrasion)	C131	15	30% max.
Percent Flat and Elongated Particles	D4791	1	10% Max
Passing sieve No.200, %	C117	1.07	-
Clay lumps, %	C142	0.42	3% Max
Fractured Pieces, %	-	96	90% Min

Table 3: Physical properties of fine aggregates.

Property	ASTM Designation	Fine Aggregate	SCRB Specification
Bulk Specific Gravity	C128	2.60	-----
Apparent Specific Gravity	C128	2.69	-----
Percent Water Absorption	C128	1.419	-----
Percent Soundness Loss by Sodium Sulfate Solution	C88	3.20	12% Max.
Passing sieve NO.200, %	C117	2.66	
Clay lumps, %	C142	2.8	3% Max
%Sand Equivalent*	D2419	49	45% min.

The Filler used in this research is a non-plastic material, mostly passing sieve No.200 (0.075 mm), typically used to enhance the properties of the mixture, increase viscosity, reduce plasticity, reduce the volume change, and crowding charges. Thus, it is characterized as an essential material. This work used limestone dust filler materials obtained from a local factory in Holly Karbala Governorate.

### 3. TESTING PROGRAM

#### 3.1 Wheel Track Test

Wheel-Track Test (WTT) has been used to measure the permanent deformation resistance following AASHTO 324, and EN 12697-22 [33,34] of the compacted mixes in a reciprocating rolling-wheel compactor device has been designed to prepare slab specimens. Wheel-Tracking Machine is used to determine the premature failure susceptibility of HMA due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage. It measures the rut depth and number of passes to failure. Also, the wheel track test can provide many indications for resistance of rutting deformation of asphalt mixtures, namely, rate of rut and dynamic stability (DS). DS refers to the number of wheel passes required to cause a unit rut depth in asphaltic mixtures. The following formula can obtain DS values:

$$DS = N15/ (D60 - D45) \tag{1}$$

Whereas:

DS: Dynamic stability (passes/mm).

N15: Number of wheel passes after the first 15 minutes of testing (passes).

D60-D45: The change in the rutting depth at the last 15 minutes of testing (mm).

This test needed two samples of 40 mm thickness that were used to obtain the average value for each mixture type, which is the temperature (60°C) was used to evaluate their effect in addition to the effects of physical properties of polymers on the performance of asphalt mixtures and to simulate local high temperature.

### 3.2 Flexural Beam Fatigue Test

Fatigue cracks are classified as one of the common failure modes in flexible asphalt pavements that affect pavement life. The flexural beam fatigue test was performed to characterize the fatigue parameters, the maximum tensile stress, maximum tensile strain, phase angle, and stiffness at load cycle intervals. The test of flexural beam fatigue is performed by applying a repeated flexural strain to an asphalt beam specimen in four-point flexural loading.

The test procedure was accomplished according to AASHTO T321, "Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending" or ASTM D7460 [35].

### 3.3 Indirect Tensile Strength Test

Asphalt pavement damage due to moisture is a serious matter that should be studied carefully. Moisture damage represents the degradation of HMA strength and their durability due to the presence of moisture or water, and it may be evaluated by losing mechanical properties. Stripping failure occurs when a poorly compacted dense-graded pavement (with >8% air voids) is subjected to repeated traffic loadings with surface water present (such as rain), and that represents the main condition for causing stripping. Calculate the tensile strength ratio to two decimal places as follows:

$$\text{Tensile strength ratio (TSR)} = S2 / S1 \tag{2}$$

Where:

S1 = average tensile strength of the dry subset, KPa (psi); and

S2 = average tensile strength of the conditioned subset, KPa (psi).

According to the following equation, the indirect tensile strength is calculated:

$$S = \frac{2000 * P}{\pi * T * D} \tag{3}$$

Where:

IDT = Indirect Tensile Strength, kPa.

P = Maximum load resistance at failure, N.

D = Diameter of the specimen, mm.

T = Thickness of specimen immediately before test, mm.

## 4. RESULTS AND DISCUSSION

CRM is obtained from the tires factory in Al-Najaf. It is a black granule (250-micron size or less) with specific gravity (1.13), and this type is recycled from used tires. The modifying process of asphalt binder by adding CRM to the binder through a wet process. Laboratory test results often give pictures that reflect the asphalt's mixture performance in an actual pavement. Traditional empirical tests have the benefit of describing bitumen's rheological attributes and mechanical behavior. The properties of asphalt binders were very complex and required many tests to describe their characteristics in the most influential operating conditions (strain and stress, temperature, loading rate). So, to simplify and to avoid this situation, traditional tests were relied upon, specifically two consistency tests. These tests are the needle penetration test in addition to other tests to characterize different grades of asphalt binder. These tests form the basis of the binder specification and provide data about the bitumen hardness or consistency without characterizing the viscoelastic response [36]. The physical properties of modified asphalt binder by rubber with a blend of (40-50 grade) asphalt binder and Crumb Rubber Modifier are needed in pavement construction. The properties are presented in Table 4.

Table 4: Physical properties of modified asphalt binder with CRM.

Property	ASTM Designation	Test result (CMR)			SCRB specification
		5%	15%	25%	
Penetration (25 °C,100 gm,5 sec) *	D-5	35	31	29	(40-50)
Ductility (25 °C, 5 cm/min). (cm) *	D-113	12.7	12.8	14	>100
Flashpoint (Cleveland open cup), (°C) *	D-92	>232	>232	>232	Min.232
Softening point, (°C) *	D-36	55	57	65	-----

\* This test was completed at the National Construction Laboratories and Research Center.

The results of physical tests presented in Table 5 indicate that the modified asphalt binder's physical properties changed dramatically when the CRM was added. This could indicate that the asphalt binder, after exposed to process mixing with the Crumb Rubber Modifier, lead to an increase in hardness due to the stiffening of the binder because absorption of some bitumen oils by rubber, which increases the viscosity of asphalt binder due to it is possible to consider penetration point test as an indirect measuring instrument of the viscosity of the asphalt binder material at 25°C, as well as using specifying different grades of binder as is the case with the concept of viscosity. Table 5 depicts the wheel tracking test results for asphalt control mixtures and modified asphalt mixtures for modified and unmodified mixtures.

Table 5: Effect of 15% CRM on Rut Depth (mm)

Mix Type	Modified Type	NMAS	No. of Cycles	Rut Depth, (mm)@10000 Cycles	No. of Cycles	Rut Depth, (mm)@1500 Cycles
Control	Control	12.5 mm	10000	15.07	1500	3.20
CRM	15%CRM	12.5 mm	10000	3.10	1500	0.90

The obtained results represent the average values of the maximum rutting depth for two samples that occur at a number of cycles (passes) of loading from WTT test, rutting depth, and number of cycles for different mixtures with or without CRM. It can be seen from Table 5 that the modified asphalt mixtures have higher permanent deformation resistance as compared with control mixtures for types of mixtures which gives a clear indication of the effect of polymers on the behavior of performance in which the (rut depth) for mixtures. The rutting resistance of modified mixtures is affected by the type and physical properties of the modifier and its concentration. Figure 1 explains the effect of polymers on dynamic stability and rutting increase rate. The results show that the dynamic stability increases by adding 15% CRM while the rutting rate decreases with the presence of CRM. The results demonstrate the ability of CRM to modify binders, which led to improving the mixtures in terms of dynamic stability. This part of the study aims to consider the influence of 15% CRM polymer modifications on the flexible pavement performance on fatigue life initial. Table 6 shows the influence of CRM on fatigue life.

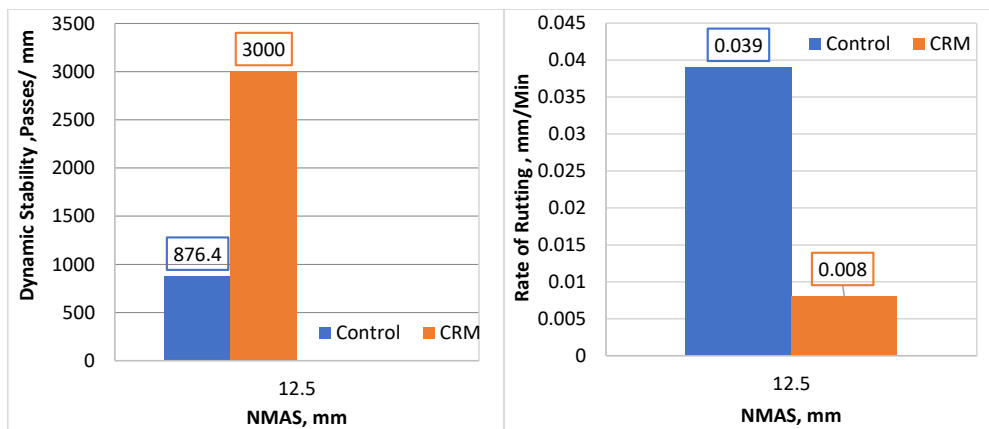


Figure 1: Effect of introducing CRM on dynamic stability and rate of rutting for 12.5mm, NMAS mixtures.

Table 6: Fatigue beam test results.

Mix type	NMAS	Asphalt content	CRM Content	Fatigue life. Nf		
				250 µε	450 µε	750 µε
C12.5	12.5	4.5	0	9100	250	126
CRM12.5	12.5	4.5	15	11500	519	468

Different strain levels were applied to show the effect of 15% CRM content blended with the binder used in this study on fatigue life under the testing temperature of 20°C. Table 6 and Figure 2 depict the effect of 15% CRM on fatigue life in the mixtures of 12.5 mm NMAS. The analysis of Figure 2 shows that when 15% CRM is used, the fatigue life increases by 21% compared to the control mix (at 250 µε, 20°C for 12.5mm NMAS mixtures). This might be because the CRM minimize the cohesion of the binder due to less affinity between rubber particle and base asphalt components. Although rubber increases the viscosity of asphalt binder and the mix strength should increase, reducing cohesion properties in asphalt binder minimizes resistance to flexural and fatigue.

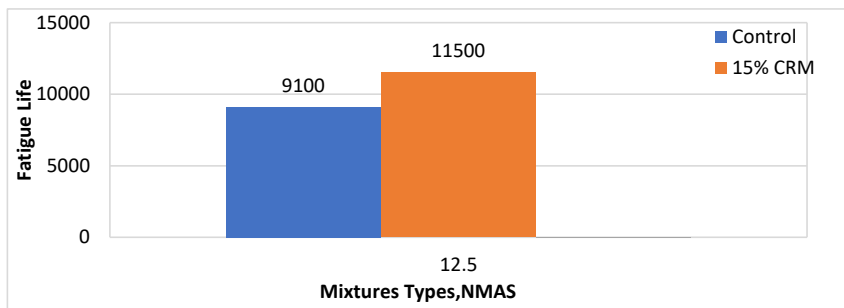


Figure 2: Effect of 15% CRM on fatigue life (N<sub>f</sub>)

Figure 2 shows the result of IDT of HMA with 15% CRM for the mixtures with different NMAS. The test results state that the IDT for HMA mixes, which 15% CRM modifies as a single pure additive, is greater than that of the control HMA mixture. This means higher values of tensile strength at failure for mixes comprising CRM, which shows greater cracking resistance strength of modified mixes in term of adhesion, improve the adhesion and cohesion properties of asphalt binder, and do not permit the striping of binder from the surface of the aggregate. That confirms by many researchers [37,38]. To assess the effect of polymer (CRM) on the resistance to moisture damage, Figure 3 shows the polymer content and Tensile Strength Ratio (TSR). The test results display that the Tensile Strength Ratio for modified mixes with 15% CRM is lower than Tensile Strength Ratio for the control mix. Of course, the CRM increases the binder film and adhesion due to increased viscosity. While this property is not satisfied with a higher NMAS mixture, the loss of cohesion affects the conditioned samples. However, it has to say that the TSR values are within the specified requirements.

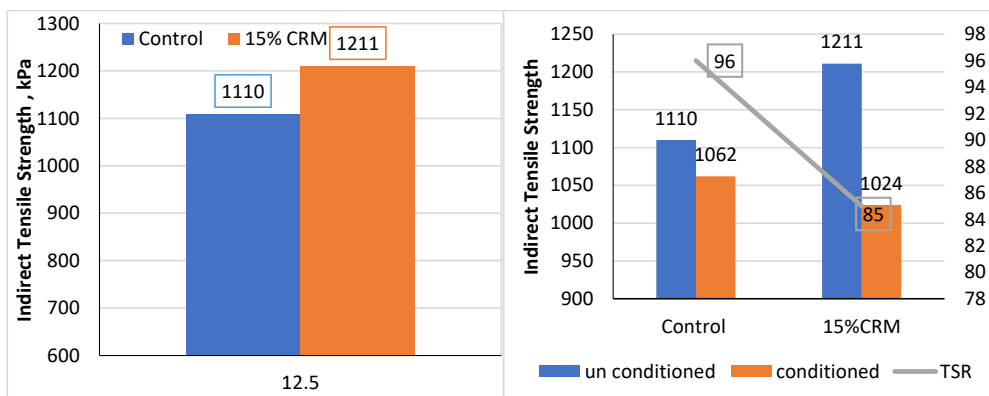


Figure 3: IDT and IDTR for 12.5mm, NMAS CRM Modified HMA Mixes.

## 5. CONCLUSIONS

- The local materials of aggregates, asphalt binder, and mineral filler that are used in the construction of flexible pavement and HMA in Iraq are accepted and laboratory tested. However, it needs improvement in the asphalt binder material used, as it plays a major role in pavement performance.
- The main problem facing specialists in the field of roads, including engineers and researchers in Iraq, is not related to the materials of aggregates included in the asphalt mixtures, but rather the matter is related to the bitumen material and how to improve it and the need to find suitable polymers and specific proportions with low costs that work to improve the performance of asphalt mixtures, and the use of waste from tires has proven that it works on Provide good results.
- Adding CRM enhances the high and intermediate temperature, the rheological characteristics of asphalt binder. After blending with CRM, asphalt binder display increased softening point, viscosity, and decreased penetration. This means the CRM-modified asphalt binder in high and intermediate temperature ranges becomes stiffer (harder) and more deformation-resistant.
- Testing methods demonstrate the ability of waste polymers such as CRM to modify binders, which improve the mixtures in terms of functionality and durability properties. The modified TAO mixtures showed the best characteristic in most mechanical, durability, and volumetric tests.

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