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Study the effect of adding crumb rubber on the performance of hot mix asphalt

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Abstract: The recycling of materials has a huge impact on the economy and the environment; therefore, the recycling of steel, aluminium, plastic and other materials have been encouraged to use in construction materials. Crumb rubber is one of these recyclable materials and has been proposed as one of the pavement components in this study since the crumb rubber can improve the pavement performance and is also considered as waste material. The most significant motivation behind use of the CRM in the pavement industry was the enhancement of pavement performance and extended service life of the pavement by increasing the resistance to moisture damage and resistance to permanent deformation and improved resilient modulus. Therefore, this study focused on the effect of CRM binders on the performance and mechanical properties of the hot mix asphalt. The CRM binders were produced by mixing asphalt binder with various percentages of crumb rubber in a wet method. There are several laboratory tests performed to assess the properties and performance of asphalt mixture, which contains various percentages of crumb rubber, and this, includes; the Marshall properties, indirect tensile strength test, moisture damage test, resilient modulus test and permanent deformation test. In this study, the results of the investigation showed that the addition of crumb rubber (CR) to the asphalt binder and used in the mixture was useful in increasing the resistance to moisture damage, improving the resilient modulus and enhancing the potential to resist permanent deformation that happens in the surface layer of the pavement as a result of increased traffic loading.

Keyword
CRM, Wet Method, Marshall Properties, Moisture Damage, Resilient Modulus and Permanent Deformation.

1. Introduction and Background

The use of the scrap vehicles tyres in the asphalt pavement industry is not a new development, use of reclaimed tyre crumb in the asphalt production has started back in the 1960s. However, the global awareness is rising in regard to the use the recycled materials to protect the environment and one of the most beneficial ways of recycling material by adding it in the construction and pavement material [1]. Therefore, the application of crumb rubber in the asphalt pavement industry obtains more attention in several countries around the world because this material provides good mechanical properties and functional performance of the pavement as well as being a proficient way of dealing with this waste product [1]. Generally, the CRM binder is kind of modified asphalt binder that contains the crumbs of waste vehicle tyres. There are several

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techniques used to produce modified asphalt mixtures by either following a wet or a dry method. In the wet method, it is recommended to use fine particle size (range from 0.075 mm to 1.2 mm) of crumb rubber to produce the CRM binders by mixing crumb rubber with asphalt at high temperatures before mixing with the aggregate. The addition of the crumb rubber into the asphalt cement leads to changes in the physical properties and chemical composition by the interactive process because the particles of rubber swell in the asphalt binder by absorbing a portion of the lighter component of the asphalt, to produce a viscous gel. In the dry method, it is recommended to use larger particle size of crumb rubber (range from 0.4mm to 10 mm). Usually, the crumb rubber is used in this method to replace a small amount of fine aggregate, which is about (1-3%) from the total weight of aggregate in the asphalt mixture. Therefore, the particles of crumb rubber are mixed with the aggregate before adding the asphalt binder into the mix. Still, in recent years, the scrap tyres problem has become serious and there is an urgent requirement to determine an ideal and effective method to use the scrap vehicle tyres in the pavements industry [2]. The most important characteristic of CRM that affect the properties and performance of mixture is a stiff of asphalt binder. Feipeng et al. found that the mixture with CRM has good resistance to moisture susceptibility, enhances resistance to permanent deformation (RD) and improves the resilient modulus to carry the moving of heavy traffic load, also had an important effect on mechanical characteristics and better than a conventional mixture [3].

2. Aims and Objectives

The purpose of this study is to explore the influence of CRM binders on the mechanical properties of the mixtures and assess the laboratory performance of the conventional mixture and mixtures, which contain various percentages of CRM binders. This would be demonstrated by evaluating the engineering properties of the asphaltic mixtures such as Marshall properties, indirect tensile strength (ITS), moisture damage (TSR), resilient modulus (Mr.), and permanent deformation (RD).

3. Experimental Programme and Testing Procedures

The experimental programme adopted in this study is detailed in figure 1, which included the use of three various percent-by the weight of asphalt cement- from CR material (5%, 10%, and 15%). It is worth mentioning that, one type and size of CR material was used and it is passing sieve (300 μm), also one type of asphalt cement with penetration grade (40-50) was used in this study and supplied from Daurah refinery, which is widely used in the pavement construction in Iraq. The properties of asphalt cement can be seen in table 1.

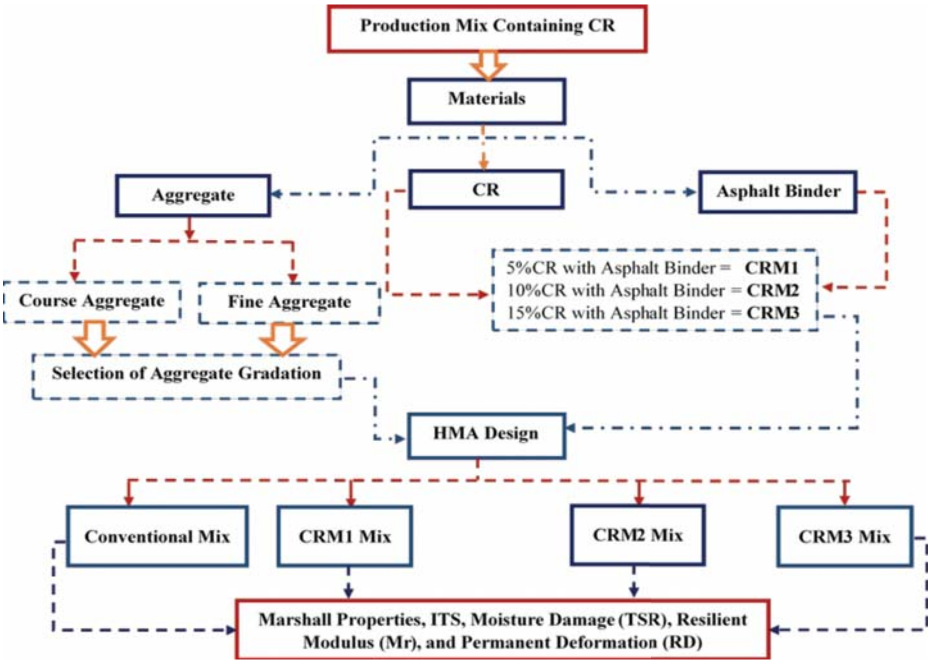

Figure 1. Flowchart for the Experimental Programme

Regarding aggregates portions, Al-Nibaee quarries were the traditional source for the coarse and fine aggregates, while limestone dust obtained from Karbala factory and utilized as the -mineral filler-. The gradation of aggregate adopted in this study to produce the asphalt mixture follows the mid-point gradation to satisfy the requirement of SORB [4] specification for the surface layer type ШA with a maximum aggregate size (19 mm) as exhibited in Table 2 and Figure 2.

Table 1. Asphalt Cement Properties

Properties	ASTM Specification 2015	Results	SORB Specification 2003
Penetration	D-5	46	**40-50**
Kinematics Viscosity	D-2170	410	**…….**
Softening Point (Ring and Ball)	D-36	51	**……**
Ductility	D-113	130	**>100**
Flash Point	D-92	272	**>232**
Specific Gravity	D-70	1.04	**…..**

Table 2. Gradation of Aggregate for Surface Layer [4]

Sieve Size	Sieve Opening (mm)	Percentage Passing by Weight of Total Aggregate	
		Specification-Limits SORB [4]	Mid-Point Gradation
3/4"	19	100	**100**
1/2"	12.5	90-100	**95**

3/8"	9.5	76-90	**83**
No.4	4.75	44-74	**59**
No.8	2.36	28-58	**43**
No.50	0.3	5-21	**13**
No.200	0.075	4-10	**7**

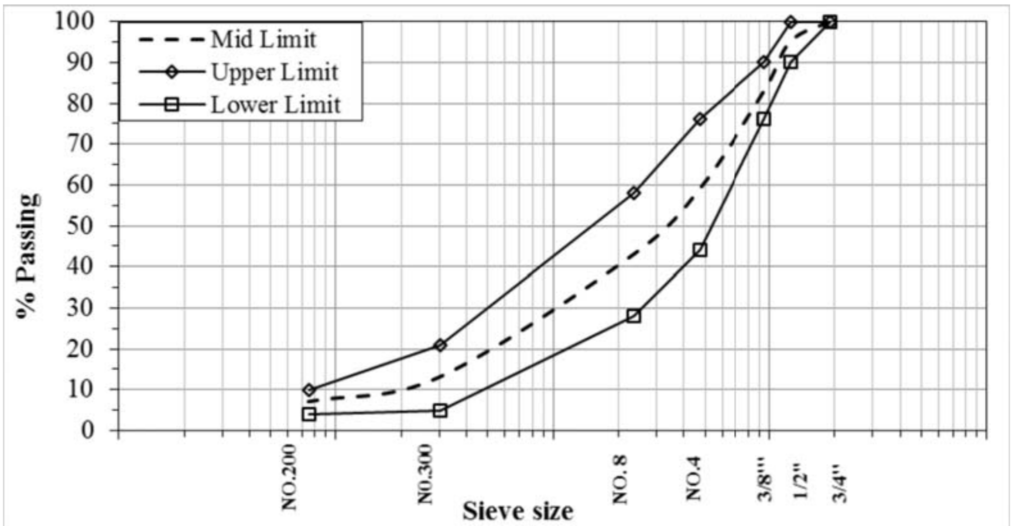

Figure 2. Gradation of Aggregate for Surface Layer and Specification Limits SORB [4]

The grinded particles of crumb rubber (CR) adopted in this study reclaimed from old used tyres at the State Company for Rubber Industries and Tyres in Babylon city. However, the basic components and properties can be seen in figure 3 and table 3. Rubbers also interact with asphalt during blending it with a binder in high temperature by a shear mixer. The wet mixing technique was applied to prepare the CRM binders that was used in the mixtures. In addition to that, it provided a chance to recycle this waste material and reduce the environmental pollution caused by disposing them [5].

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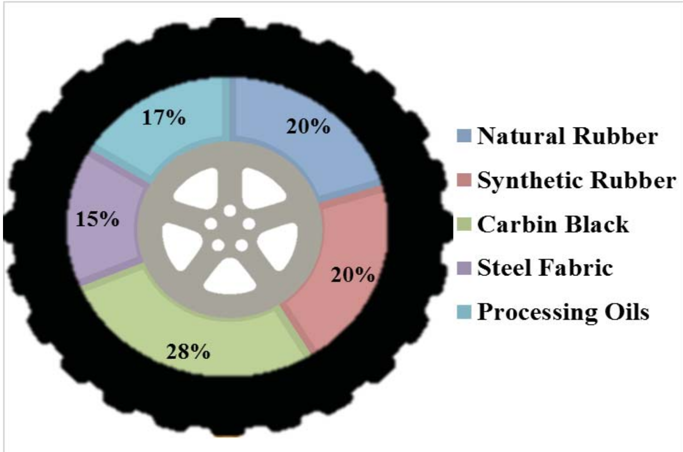

Figure 3. Average Percentage Components of Tires Adopted from [6]

Table 3. The Properties and Compositions of CR Used in this Study

Component	Typical Range [6]	Characteristics	
Natural Rubber	14% to 27%	Density	1.14
Synthetic Rubber	14% to 27%	Sulfur Content	1.77
Carbon Black	28%	Polymer Base (N, S,B)	60, 20, 20
Steel, Fabric	14% to 15%	**Composition**	
Processing Oils	16% to 17%	Rubber %	65.86
		Carbon Black%	28.72
		Ash Content %	5.42

The Marshall method of mix design adopted to calculate the optimum binder content (O.B.C) required to be added in the conventional mixture, and mixtures, which contain different percentages of CR material to prepare mixtures with good properties to resist the permanent deformation (RD), moisture damage, and resilient modulus. Furthermore, the specimens prepared should meet the volumetric properties demanded, which involved air-voids (Va), voids filled with asphalt (VFA), and voids in mineral aggregates (VMA). The optimum binder content of HMA with conventional mixture was found to be (4.8%), with mixtures containing (5% CR) was (5%) and for (10% CR) was (5.2%) and for (15% CR) was (5.6%) as presented in table 4.

Twelve specimens prepared according to ASTM [7] and adopted to evaluate the mechanical and volumetric properties of the mixtures. Twenty-four specimens prepared according to ASTM [7] for conditioned and unconditioned ITS with air-voids (4±1%), and adopted to assess the moisture susceptibility of mixtures according to ASTM [7] procedures. The cylindrical specimens were prepared in the laboratory with dimensions (101.6mm) diameter and (152.4mm) height by the gyratory compactor, twenty-four specimens were compacted according to the traffic levels (3-30 million) ESAL for Baghdad-Iraq at (Ninitial=8 gyrations, Ndes.=100 gyrations, and Nmax.=160 gyrations) and adopted to assess the resilient modulus (Mr.). The wheel tracking slabs were prepared in the laboratory with dimension (400mm) in length, (300mm) in width and (50mm) in height according to European standard EN [8]. Three slabs for each mixture type has been tested according to European standard EN [9] in this study and adopted to assess the permanent deformation (RD).

Table 4. Asphalt Mixtures Properties

Mixture Type	Asphalt Content (%)	Bulk Density gm/cm^3	AV%	VMA%	VFA%
Conventional	4.8	2.345	4.24	15.21	72.1
CRM1	5	2.348	4.19	15.28	72.56
CRM2	5.2	2.352	4.15	15.31	72.89
CRM3	5.6	2.362	4.11	15.31	73.16

4. Experimental Results and Discussions

4.1. Volumetric Properties Analysis

The volumetric parameters of the asphalt mixtures have a significant effect on its performance; therefore, the volumetric result values (e.g. air-voids (V), voids in mineral aggregate (VMA) and voids filled with asphalt (VFA)) can be seen in table 4. From the table mentioned above, it can be observed that the bulk density for the conventional mixture and the CRM mixtures increase with increasing CR content. Air-voids values (Va) for all mixtures are lower than the conventional mixture and significantly affected by the percentage of asphalt content in the mixture and bulk density. However, it can be noticed there is no significant difference between the voids in mineral aggregate (VMA) and voids filled with asphalt (VFA) in the conventional mixture and CRM mixtures in line with [3] and [10].

4.2. Marshall Stability and Flow Analysis

All the specimens met the minimum Marshall stability standard of (8kN) for the surface pavement layer type ШA and high traffic volume, also, the air-voids and bulk density satisfied the requirements specification of SORB [4]. Therefore, all the mixtures prepared in this study meet with the Marshall flow standards of (2-4mm). The Marshall stability and Marshall flow values for all the mixtures are displayed in figures 4 and 5. These results indicate that increasing of CR content in the mixtures led to improving the Marshall stability and reducing the Marshall flow compared with the conventional mixture. Those increases in the Marshall stability values for CRM binders may be related to making the mixture more stiffer than the conventional mixture and may be associated by the good interlocking offered between the asphalt and aggregate particles and this led to the reduction in the fluidity of the binder and increased stability and improvement in other properties [3].

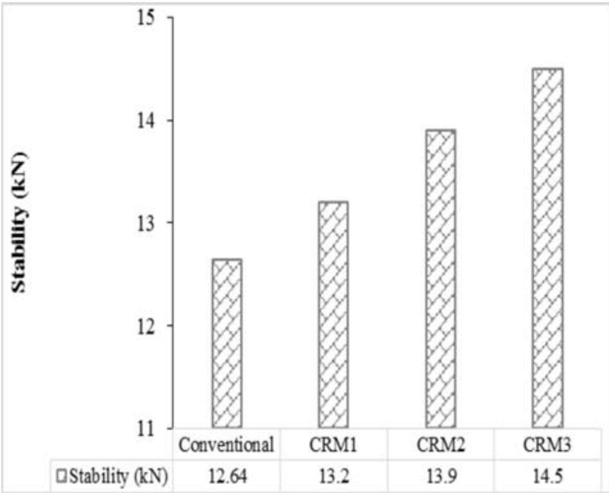

Figure 4. The Behaviour of Marshall Stability

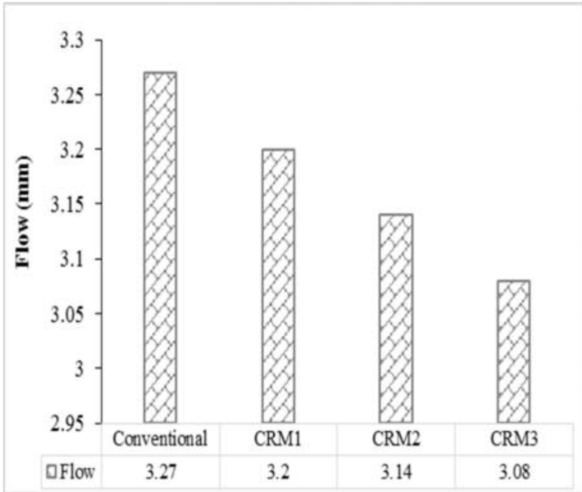

Figure 5. The Behaviour of Marshall Flow

4.3. Moisture Susceptibility Analysis

One of the important factors affecting the durability of asphaltic pavement is the moisture damage. Commonly, the asphaltic pavement must have the ability to carry heavy traffic loads under certain climatic conditions and to resist any deformation during whole pavement service life in order to meet the performance requirements. The loss of the adhesion bond between the asphalt binder and aggregate interface or collapse of the cohesion of asphalt binder is the final step to transport the various patterns of moisture into the interior structure of the asphaltic pavement system that leads to loss in the functionality performance of the pavement.

The conventional mixture and CRM mixtures were subjected to ITS and measured the TSR by dividing the conditioned specimens to the unconditioned specimens to assess the effect of increasing the CR content on the resistance to the water damage by these tests. Figure 6 presents the ITS for unconditioned and conditioned specimens and can be seen that the ITS for unconditioned specimens more than the ITS for conditioned specimens. Also, the ITS improved with increasing CR content in the mixture compared with the conventional mixture and this led to enhancing the resistance to moisture damage. Because the CR material increased the viscosity of asphalt binder that made the bond between the CRM binder and aggregate become stronger. Eventually, the stronger bond led to reducing water absorption and increased moisture damage resistance [11].

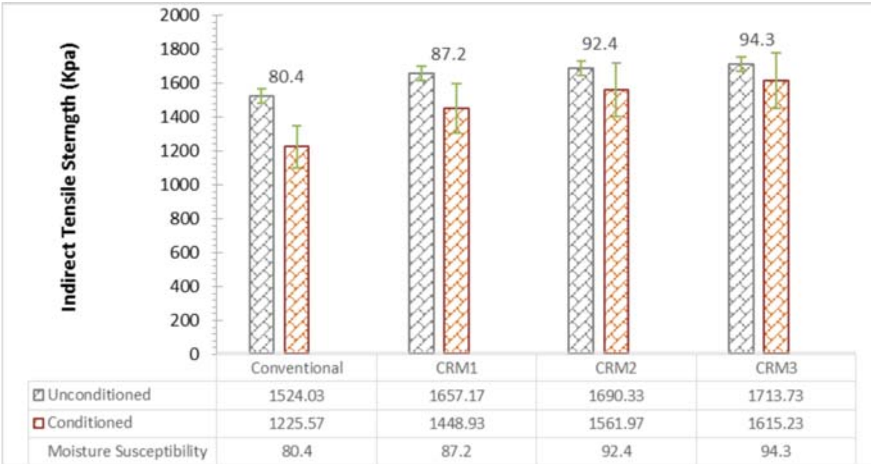

Figure 6. The Effect of CR on the ITS and Moisture Susceptibility

4.4. Resilient Modulus Analysis

Resilient Modulus (Mr.) is one of the common properties of asphaltic pavements and can be adopted to predict the response of the materials to repeated impulse or moving loads, this is represented as a simulation for moving vehicle tyres on the road surface. Whereas, the resilient modulus (Mr.) is defined as the ratio of applied stress to the recoverable strain that occurs after removing the applied stress [12].

Figure 7 illustrates the resilient modulus for all the mixtures used in this study with different CR content, and it can be observed that the addition of CR results in a notable improvement in the resilient modulus value at the same temperature. It is worth mentioning that as the temperature increases, the resilient modulus notably decreases regardless of the CR content, and that means the resilient modulus for (40ºC) more than the resilient modulus for (50ºC) because the resilient modulus is affected by temperature and this increase is related to increasing stiffness at low temperature. Therefore, it can be seen that the resilient modulus for all the mixtures, which contain CR were greater than the conventional mixture, because the adding of CR led to increasing the asphalt binder viscosity and this caused the increase in the stiffness of the mixtures and all of that led to an increase in the resilient modulus [3] and [13].

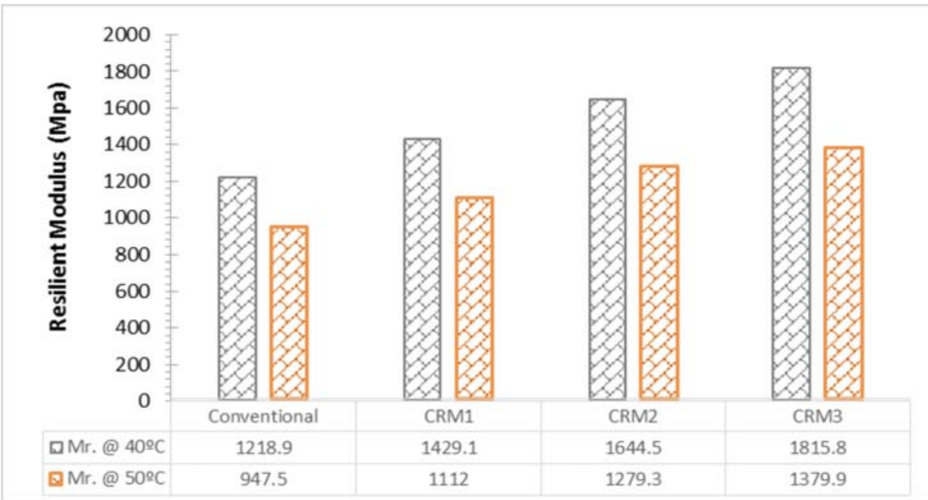

Figure 7. The Effect of CR on the Resilient Modulus

4.5. Permanent Deformation Analysis

Permanent Deformation (RD) in the flexible pavement is described as an accumulation of small amounts of unrecoverable deformation in the HMA that is mainly created by high traffic loading after construction. In order to achieve the high resistance for permanent deformation, a stiffer asphalt binder (high viscosity and low penetration) should be used. That can be obtained by using some admixture (e.g. polymer or CRM binders) to ensure a stiffer asphalt and that made the mixture more resistant to permanent deformation [14], [15] and [16]. In this study, the permanent deformation of the asphaltic specimens was measured at each cycle by using a data recorder system (LVDT) for 10000 cycles. Therefore, for all testing specimens, the failure of the device was described as the number of cycles required to achieve the permanent deformation (RD) equal to (25mm) or complete the number of the cycle at 10,000 cycles. As shown in figures 8 and 9, the conventional specimens showed a notably permanent deformation more than what the other modified specimens do. In addition, it can be seen that the permanent deformation increased notably for a first (4000 cycles) and then the increase of permanent deformation grows more gradual. It is worth mentioning that the temperature can affect the permanent deformation significantly regardless of the CR content, and that means the permanent deformation for (50ºC) is more than the permanent deformation for (40ºC).

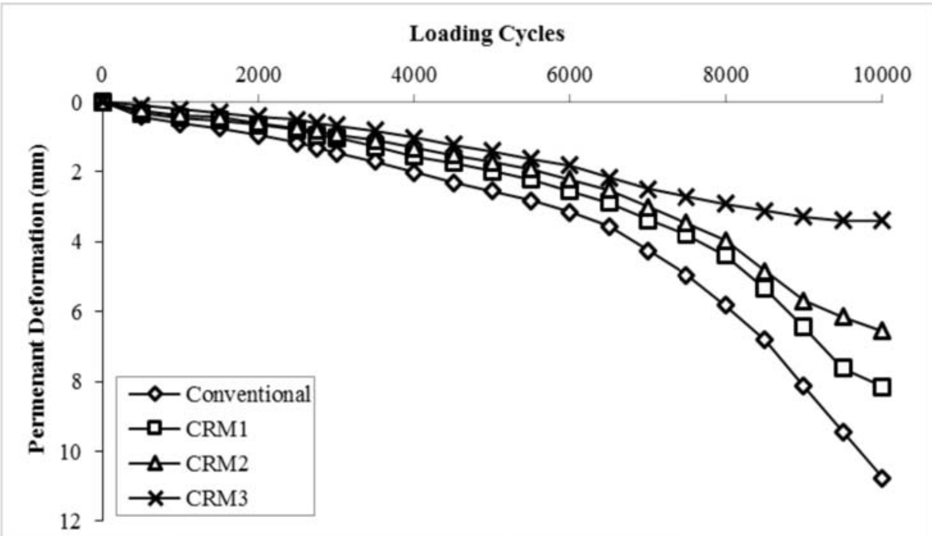

Figure 8. The Permanent Deformation Behaviour of Modified Mixtures at (40ºC)

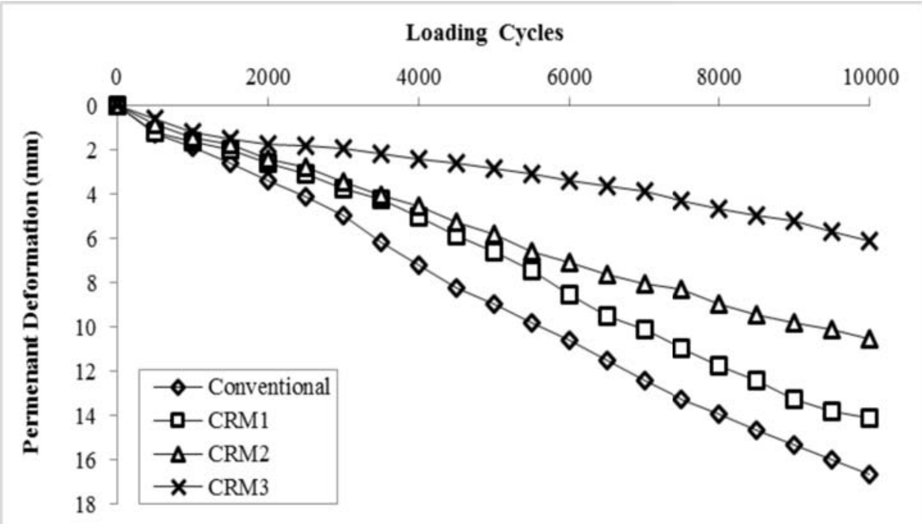

Figure 9. The Permanent Deformation Behaviour of Modified Mixtures at (50ºC)

However, it can be seen that the addition of CR gave an important role in decreasing the effect of temperature on the permanent deformation for the mixture. Therefore, CRM mixture is more efficient in enhancing the resistance to permanent deformation than the conventional mixture [3].

5. Conclusions

Depending on the data results from a laboratory investigation; the conclusions in this study are drawn as follows:

1. In Marshall mix design, high CR content -in the mixture- tend to have a higher Marshall stability and a lower Marshall flow than the conventional mixture resulting in improved volumetric properties.
2. The durability of asphaltic pavements to resist moisture damage was evaluated by -ITS- test. The results showed that the addition of CR material in the mixture improved the -ITS and TSR- values, and hence, increased the resistance of HMA mixture (which contains CR) to moisture damage.
3. Use of CR material enhanced the resilient modulus values regardless of temperatures, and had a greater resilient modulus than the conventional mixture. Therefore, increasing the temperature test from 40°C to 50°C substantially reduced the resilient modulus, and this effect decreased with increasing the CR content.
4. The CR material gave a significant role in improving the resistance of HMA to permanent deformation. Since the addition of the CR material led to a substantial enhancement in the performance of HMA. On the other hand, it reduced the influence of permanent deformation by the temperature.

Finally, according to the experimental work presented in this study and its limitation, it is recommended to use the CRM binder in the construction of HMA pavement, especially in the hot climate regions such as the Middle East as it can perform well under high temperatures.

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