Development of Sustainable Asphalt Pavement Mixture Using Recycled concrete aggregate, Crumb Rubber and Waste Engine Oil

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A B S T R A C T

The incorporation of crumb rubber derived from waste tires into asphalt mixtures is an effective strategy for improving the fatigue resistance of asphalt pavement. This research focused on hot mix asphalt (HMA) mixtures that replaced 40% of natural aggregate (limestone) with recycled concrete aggregates (RCA) treated with waste engine oil (WEO). Two types of asphalt binders were used: traditional AC60-70 and the same binder modified with 3%, 4%, and 5% crumb rubber (CR) by the weight of bitumen. The study aimed to investigate the influence of CR polymers on asphalt pavement performance and explore the feasibility of using WEO for asphalt modification. Various asphalt mixtures with different CR percentages were tested to evaluate their mechanical properties, including stability, fatigue resistance, permanent deformation, and loss of stability. The durability and resistance of the asphalt mixtures were also assessed through indirect tensile strength testing before and after exposure to water. The study found that the CR-modified mixes showcased several advantages compared to conventional mixes. These included enhanced fatigue and permanent deformation properties, reduced susceptibility to temperature variations, and improved resistance to moisture damage. Overall, the CR-modified mixes demonstrated improved performance compared to the regular mixes. The results indicated that the developed HMA, which included 40% RCA and 4% crumb rubber binder, improved stability and the Percentage of Indirect Tensile Strength Ratio (ITSR). Among the different CR percentages tested, the 4% crumb rubber modification demonstrated the highest fatigue life. Furthermore, the addition of 3% waste engine oil to the modified control mix (MCM) with 40% RCA and 4% CR appeared to enhance the durability of the asphalt mixture. Ultimately, the utilization of MCM with 40% RCA, 4% CR, and 3% WEO was found to enhance the performance of the asphalt pavement mixtures that were developed.

Keywords: Crumb rubber; Waste engine oil; Recycled concrete aggregates; Hot mix asphalt; Developed asphalt pavement Mixture.

1. INTRODUCTION

The use of waste and secondary materials in hot mix asphalt (HMA) has gained recognition for its mechanical and environmental advantages. Various studies, including those materials have highlighted the positive attributes of using materials such as construction and demolition waste in HMA [1,2,3]. These materials offer both mechanical and environmental benefits, making them an attractive choice for asphalt production. The studies emphasize the potential of incorporating waste and secondary materials into HMA to improve its performance and reduce environmental impact [4]. The use of recycled waste materials in road pavement is gaining popularity as it offers several benefits related to sustainability and improved performance. This approach is becoming recognized as an appealing option for road construction. By incorporating recycled waste materials into pavement, we can promote sustainability by reducing the demand for virgin materials and minimizing waste disposal. Additionally, these recycled materials have the potential to enhance the performance of road surfaces, resulting in improved durability and cost-effectiveness. Overall, the utilization of recycled waste materials in road pavement is seen as a promising and environmentally friendly solution [5]. The utilization of CR derived from discarded tires to enhance the mechanical properties of bituminous mixtures has become highly significant in the field of road engineering. In recent years, extensive research has been conducted to understand the influence of CR on pavement performance. By incorporating crumb rubber into bituminous mixtures, engineers aim to enhance the properties and performance of road surfaces. This research focuses on investigating how the addition of crumb rubber affects important factors such as durability, flexibility, skid resistance [6,7,8]. The incorporation of CR derived from waste tires into asphalt mixtures is considered a successful strategy for enhancing the fatigue resistance of asphalt pavement [6,9]. This approach has gained popularity due to its potential in improving mix performance and addressing waste tire disposal issues. Crumb rubber can be incorporated into asphalt mixes through two methods: the dry process, where rubber crumbs are mixed with aggregates, or the wet process, where rubber crumb is blended with bitumen at a specific temperature to modify the binder. The wet process of crumb rubber modification has shown promising results in improving the rutting resistance, resilience modulus, and fatigue cracking resistance of asphalt mixes. This is achieved by altering the properties of the bituminous binder, such as viscosity and softening point. By modifying the binder, the overall performance of the asphaltic mixes can be enhanced, leading to improved durability and resistance to distresses commonly observed in asphalt pavements [10]. Crumb rubber modified asphalt mixture needed less bitumen content. Therefore, CR is suitable to use with modified control mix with 40% RCA to reduce the bitumen content in this mixture. Crumb rubber modified bitumen should not be utilized on low-volume roads as it can negatively impact their durability [11]. The effect of using the crumb rubber of three different percentages (3% - 4% - 5%) by weight of bitumen added to asphalt during mixing in behavior of asphalt mixture (AM) is investigated in this research. Various laboratory tests have been developed to predict and compare the mechanical and engineering properties of asphalt mixes under different loadings and environmental conditions [12]. Also for the predicting and evaluating the long-term performance of asphalt mixes, four mechanical properties were investigated which are the stability, fatigue resistance, permanent deformation and loss of stability. Marshall stability and flow tests were conducted on the samples to evaluate their performance. The recycling of waste engine oil (WEO) in asphalt has multiple benefits, including the conservation of non-renewable crude resources, reduction of CO_2 emissions, and promotion of ecological economy. Globally, car services generate approximately 40 million tons of WEO annually. Currently, traditional methods of handling WEO involve either recycling it to produce new engine oil or simply discarding it, with more than half of the WEO becoming waste. This waste has detrimental effects on human health and water resources. However, due to expensive costs and pollution concerns, traditional recycling technologies for WEO are limited [13]. WEO is used with different percentages (3,4,5%) by weight of asphalt binder to investigate its effect on the performance of asphalt mixture.

2. PROBLEM DEFINITION

The research problem addressed in this study revolves around the high cost of materials used in hot mix asphalt and the poor quality and durability of flexible asphalt in Egypt. Specifically, the focus is on the occurrence of cracks, which lead to increased expenses for road repairs. The presence of cracks and other damages shortly after construction has significantly raised the cost of maintaining roads in Egypt. This issue highlights the need to improve the quality and durability of asphalt pavements to reduce the occurrence of cracks and subsequent costly repairs.

3. RESEARCH OBJECTIVES

In order to evaluate the possibility of using CR and WEO to develop the modified hot mix asphalt (MHMA) with 40% RCA, the main objectives of this study were to:

1- Develop modified binder to resist fatigue using crumb rubber (CR) in modified hot mix asphalt with 40% RCA.

2- Enhance asphalt mix workability and cost using waste engine oil (WEO).

3- Decreasing the cost of materials used in HMA and maintenance cost of asphalt.

4. MATERIALS, TEST EQUIPMENT, & METHOD

4.1 Materials

4.1.1 Bitumen

In this study, researchers used 60/70 penetration grade bitumen sourced from Suez to create samples for testing. They conducted laboratory tests to assess the physical characteristics of the bitumen, as shown in Figure (1). The obtained results, along with their corresponding limits, were compiled and presented in Table (1).

Table 1: Physical Properties of Used Bitumen

Properties	Values	Specifications
Penetration at 25 ^{o}C (0.1mm)	62	60/70
Kinematic Viscosity at 135 ^{o}C	356	320
Softening Point	48	45/55

Figure (1): The Used Bitumen (60/70 penetration grade)

4.1.2 Aggregate

In this study, commonly crushed aggregate obtained from Atta'a mountain was used. Several experiments and tests to investigate the physical characteristics of the aggregate were conducted. Gradation tests were specifically employed to analyze the distribution of sizes within the aggregate. The conducted tests have provided significant data regarding the physical properties of the aggregate, which are presented and summarized in Table (2).

Table 2: Physical Properties of Used Aggregate

Properties	Aggregate Size		
	(6 - 9) mm	(9 – 13) mm	(13 - 25) mm
specific weight	2.40	2.70	2.60
saturated-dry surface	2.45	2.58	2.61
Apparent specific weight	2.68	2.72	2.73
water absorption%	1.3	2.87	2.57
Bulk density (t/m^3)	2.31	2.53	2.54
Abrasion	0.85	0.65	0.69

4.1.3 Recycled Concrete Aggregate (RCA)

RCA refers to granular materials obtained from the demolition of buildings and structures. In this particular study, RCA was obtained from the demolition of a strip beam in the Housing and Building National Research Center (HBRC). The RCA used in this research was classified as such because 98% of the material had a nominal size greater than 4.75mm. A study conducted by Saad et al. in 2023 investigated the impact of using RCA on the performance of asphalt pavement mixtures. The results indicated that a modified control mix (MCM) containing 40% RCA by weight of the total aggregate achieved appropriate Marshall stability and flow values. Additionally, this MCM demonstrated the lowest permanent deformation value compared to the conventional mix (CM). The research concluded that adding 40% RCA to the asphalt mixture in place of natural aggregate was beneficial, as previously concluded by Saad et al. in their previous work. Several tests were conducted to evaluate the physical properties of the RCA used in the study, and the summarized results are presented in Table (3).

Table 3: Physical Properties of Used RCA

Test	Method	Value
Specific gravity – coarse aggregate	AASHTO T 84-00	2.200
Absorption – coarse aggregate	AASHTO T 84-00	3.670
Specific gravity – fine aggregate	AASHTO T 85-91	2.420
Absorption – fine aggregate	AASHTO T 85-91	3.690
Abrasion in Los Angeles machine	AASHTO T 96-02	22.28
Shape index	DNER-ME 086/94	0.70

4.1.4 Crumb rubber (CR)

In the study, crumb rubber (CR) derived from waste tires was utilized, specifically with a particle size falling within the range of 0.6 to 0.65 mm. The researchers added different percentages of CR (3%, 4%, and 5% by weight of bitumen) to the asphalt mixtures. Laboratory tests were conducted to assess the physical properties of the modified bitumen. The findings of these tests are presented and summarized in Table (4). The table likely includes data on various parameters such as viscosity, softening point, penetration that were measured to evaluate the performance of the modified bitumen.

Table 4: Physical Properties of Modified Bitumen

Properties	With 0% CR	With 3% CR	With 4% CR	With 5% CR
Penetration at 25 ^oC (0.1mm)	62	57	49	44
Kinematic Viscosity at 135 ^oC	356	977	2345	4300
Softening Point	48	51	55	58

4.1.5 Waste Engine Oil (WEO)

The use of WEO in asphalt mixture has multiple benefits. Firstly, it helps conserve non-renewable natural crude resources. Additionally, it aids in reducing CO2 emissions, thus contributing to environmental sustainability. By promoting the utilization of WEO in asphalt, ecological sustainability is further supported [6]. The waste engine oil used in the study was obtained from car workshops. To ensure its suitability for asphalt production, the WEO was sieved through a No. 200 sieve to remove any particles or impurities. The researchers conducted tests on the WEO to determine its viscosity, specific gravity, and water content. The results of these tests are provided in Table 5, which likely presents the measured values for each parameter, providing insights into the quality and characteristics of the recycled waste engine oil.

Table 5: Properties of waste Engine oil

Test	Value
Viscosity (CP)	165
Specific Gravity	0.94
Water content (%)	0.29

5. METHODOLOGY

According to the EGYPTIAN CODE specifications, aggregates are banded together in order to get a proper gradation. The percentage of each type of aggregate is computed and compared to specification limits.

5.1 Marshall Stability and flow (T245)

The AASHTO standard T245 is utilized for a specific test, known as AASHTO T 245 [16]. The test involves preparing Marshall specimens by subjecting aggregates and recycled concrete aggregate (RCA) to a temperature of 160°C for 2 hours to eliminate moisture content. The bitumen is also heated at the same temperature and time. The specimens weigh 1.2 kg and are prepared based on the mix components outlined in Table (6). The mixture is then heated using a fire flame at 150°C. The materials are added to a metallic bowl in the following sequence: coarse aggregate first, followed by fine aggregate and filler (stone dust), and finally, the bitumen.

Table 6: Mix components in Marshall test for MCM with 40% RCA

Mix Components	Percentage of Components (percent)	Mix Components (gm)
BIN (13 -25mm)	5%	60
BIN (9 -13mm)	12%	144
Sand (0 -6mm)	18%	216
C. Sand (0-6 mm)	10%	120
BIN (6 -9mm)	15%	180
RCA	40%	480
Bitumen60/70	5%	60
Total weight of specimen		1200

The materials were mixed in a bowl using a mixer for around 3.5 minutes at a constant rate of 100 rpm. Once the mixing process was completed, the mixture was manually transferred into a metallic bowl and placed back into the oven at the same temperature for 1 hour using Marshall moulds. After an hour, the mixture was placed into the Marshall moulds and compacted by applying 75 blows on each side of the specimen using a Marshall Hammer. After compaction, the specimens were allowed to cool to ambient temperature, and then mechanically extracted from the moulds. In the end, Marshall specimens of the asphalt mixture type were successfully manufactured.

5.2 Indirect tensile strength (ITS)

According to the standard EN 12697-12, ITS test is conducted on a compacted asphalt mix slice to assess its durability and resistance [17]. The test is performed before and after exposing the sample to water. In this study, six samples were tested: three dry samples and three wet samples of a modified control mix (MCM) containing 40% recycled concrete aggregate (RCA). The purpose was to observe the change in indirect tensile strength (ITS). Another set of six samples, consisting of three dry samples and three wet samples, were tested using the modified control mix (MCM) with 40% RCA

and 4% crumb rubber (CR). The same ITS test was conducted to assess the change in strength.
The indirect tensile strength test involves attaching a sample between two load stripes and applying a radial load at a speed of 50mm/min until the sample fractures. The maximum load at the point of fracture is recorded. The Indirect Tensile Strength Ratio (ITSR) is then estimated as the ratio of the strength values obtained after water storage to the strength values before water storage using the following equation.

$$\text{ITSR}(\%) = \frac{\text{ITSR wet (MPa)}}{\text{ITSR dry (MPa)}} * 100$$

5.3 Loss of stability test

The loss of stability test, a simplified version of AASHTO-T165, was conducted to assess the durability of asphalt mixes by measuring their resistance to moisture damage [18,19,20]. This test evaluates the loss of stability in compacted asphalt mixtures caused by water exposure. The stability of dry specimens is being compared to specimens that have undergone immersion in a water bath at a temperature of 60°C for a duration of 24 hours. In this study, six samples were tested: three dry samples and three wet samples that had been immersed in the water bath. These samples were taken from a modified control mix (MCM) containing 40% recycled concrete aggregate (RCA). The purpose was to evaluate the loss of stability in this mix. Additionally, another set of six samples, consisting of three dry samples and three wet samples that had been immersed in the water bath, were tested. These samples were taken from the modified control mix (MCM) containing 40% RCA and 4% crumb rubber (CR). The aim was to assess the loss of stability in the tested mix. The loss of stability (%) is then calculated using the following equation.

$$\text{Loss of stability } (\%) = 100 - \left(\frac{\text{Stability wet(kg)}}{\text{Stability dry (kg)}}\right) * 100$$

5.4 Permanent deformation (the creep) test

The permanent deformation test, also referred to as the creep test, is used to examine how a material deforms under compression [21]. It involves measuring the deformation characteristics of a material. In this specific study, the test was conducted using a consolidation-testing machine. Some adjustments were made to the machine to accommodate the size of the test specimen, which in this case was a Marshall specimen. To establish the starting conditions of the test, each specimen was pre-loaded with a weight of 8.16 kg (18 lb) for 2 minutes, resulting in a preconditioning stress of 0.01 MPa. This step helped to press the protruding parts and ensure consistent starting conditions. The actual test involved applying a constant vertical stress level (σ = 0.1 MPa) to the axial direction of the specimen. The test maintained a constant stress level for a duration of 60 minutes at an ambient temperature of 20°C. In order to quantify the total vertical deformation (ΔH) induced by the static load, a dial gauge with a precision of 0.01 mm was utilized. Deformation readings were recorded at specific loading times, such as 5, 10, 15, 20 minutes, and so on, until reaching the 60-minute mark. This measurement technique was similar to previous studies conducted by Abdel-Motaleb and Mohamudy et al. [22,23,24]. Figure (2) shows the rutting test machine.

Figure (2): Rutting Test Machine

5.5 Fatigue test (The double punching test)

The double punching test (DPT) is a method used to assess the fatigue Characteristics of asphalt mixtures [25]. It involves using cylindrical specimens of asphalt mixture with specific dimensions, known as Marshall cylindrical specimens. These specimens measure 101.6 mm in diameter and 63.5 mm in height. The purpose of the DPT is to determine the tensile strength (σt) of the asphalt mixture at a temperature of 20°C, which serves as an indication of its fatigue behavior.
During the DPT, a cylindrical specimen is positioned between two steel punches. Each punch has a diameter of 25 mm. The specimen is then subjected to vertical loading at a rate of 1.27 mm/min until it collapses or fails. By measuring the tensile strength (σt) value obtained from this test, valuable information can be obtained regarding the fatigue resistance of the asphalt mixture.

$$\sigma t = P / \pi \ (1.2bH - a\ 2)$$

6. RESULT & ANALYSIS

The modified control specimens with 40% RCA and without crumb rubber and the modified control specimens containing 40 % of recycled concrete aggregate with different ratios (3,4, and 5 %) of CR as a bitumen modified were tested for volumetric and physical properties in Marshall Stability test to calculate stability and flow values [16,26].

6.1 Stability and flow results for Modified Control Mix containing 40% RCA & different bitumen ratio

The stability of an asphalt mix refers to the maximum load needed to cause failure of the specimen when a constant rate of 50 mm/min is applied. The results of this test are presented in Table (7). Based on these results, the asphalt mix achieves a maximum stability of 965 kg at a bitumen content of 5%. Furthermore, the maximum flow of this mix is recorded as 2.6 at the same bitumen ratio, which is determined to be 5% of the total mix weight. This bitumen content value is calculated by averaging the bitumen content values associated with the maximum stability, maximum density, and median of the air voids.

Table 7: MCM with 40% RCA for Different Bitumen Ratio (%)

RCA 40% Bitumen%	Unit weight (gm)	Air Voids %	VMA%	Stability (kg)	Flow (mm)
4.5	2.16	5.2	17.7	750.94	2.35
4.75	2.18	4.8	17.5	909.91	2.48
5.0	2.23	3.6	16.08	965	2.6
5.25	2.24	3.1	15.27	810.76	2.64

6.2 Stability and flow results for MCM containing 40% RCA, different bitumen ratios & modified bitumen ratios

Tables (8 & 9 & 10) present the mechanical properties for MCM with 40% RCA and different modified bitumen with CR percentages (3 & 4 & 5%) by weight of asphalt binder.

Table 8: MCM with Different Bitumen Ratio (%) and 3% CR by weight of asphalt binder

RCA 40% Bitumen% With 3% CR	Unit weight (gm)	Air Voids %	VMA%	Stability (kg)	Flow (mm)
4.5	2.2	6.29	16	726	1.22
4.75	2.22	5.71	14.8	740	1.4
5.0	2.25	4.34	13.7	990	2.12
5.25	2.26	3.88	14.1	680	2.22

Table 9: MCM with Different Bitumen Ratio (%) and 4% CR by weight of asphalt binder

RCA 40% Bitumen% With 4% CR	Unit weight (gm)	Air Voids %	VMA%	Stability (kg)	Flow (mm)
4.5	2.17	7.5	15.2	725	1.18
4.75	2.21	6.2	14.2	845	1.56
5.0	2.23	5.2	13.5	1030	2.07
5.25	2.24	4.9	13.9	756	2.12

Table 10: MCM with Different Bitumen Ratio (%) and 5% CR by weight of asphalt binder

RCA 40% / Bitumen% With 5% CR	Unit weight (gm)	Air Voids %	VMA%	Stability (kg)	Flow (mm)
4.5	2.17	7.66	15.3	818	0.22
4.75	2.18	7.14	15.06	1186	0.67
5.0	2.19	7.1	14.7	1204	1.03
5.25	2.2	6.49	14.9	781	1.25

Table 11: Stability & Flow & Rigidity Outcomes for CM & MCM with 40 %RCA and Different CR Percentages by weight of asphalt binder

CR percentage (%) with 40 % RCA	Optimum Bitumen%	Stability (kg)	Flow (mm)	Rigidity (kg/mm)	Cost (L.E)
0%	5	965	2.6	370	1970
3%	4.84	990	2.12	466	1928
4%	4.8	1030	2.07	497	1915
5%	4.75	1204	1.03	1168	1898

The study examined the results of Marshall stability and flow tests comparing CM (conventional mixture) and MCM with 40% RCA and varying percentages of CR by weight of asphalt binder as a bitumen modifier. The cost factor, based on the percentage of bitumen in the asphalt mixture, was taken into consideration. The findings indicate that the MCM containing 40% RCA and 4% CR offers the lowest cost among all the modified mixtures, amounting to 1915 Egyptian pounds per m3 of asphalt. Figures (3, 4, and 5) display the measurements of stability, flow, and rigidity for the MCM with 40% RCA and different percentages of CR. The cost for cubic meter of MCM with different percentages of CR is shown in Figure (6).

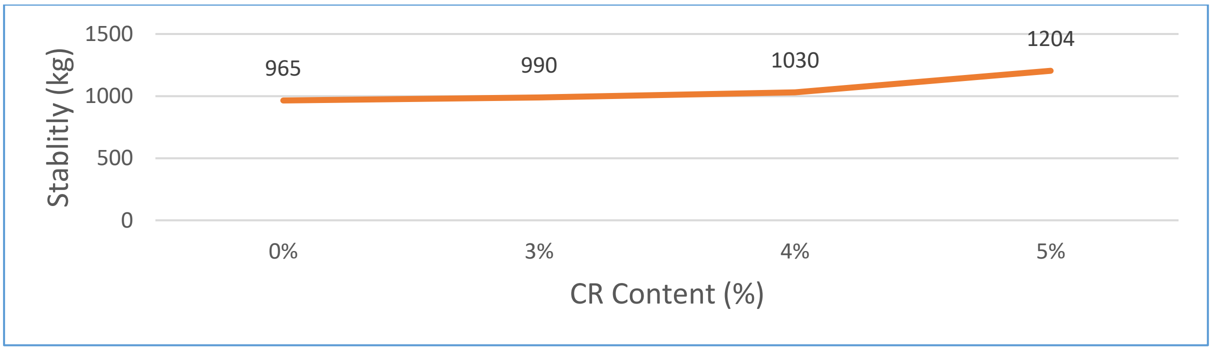

Figure (3): Stability for MCM with 40% RCA & Different percentages of CR by weight of asphalt binder

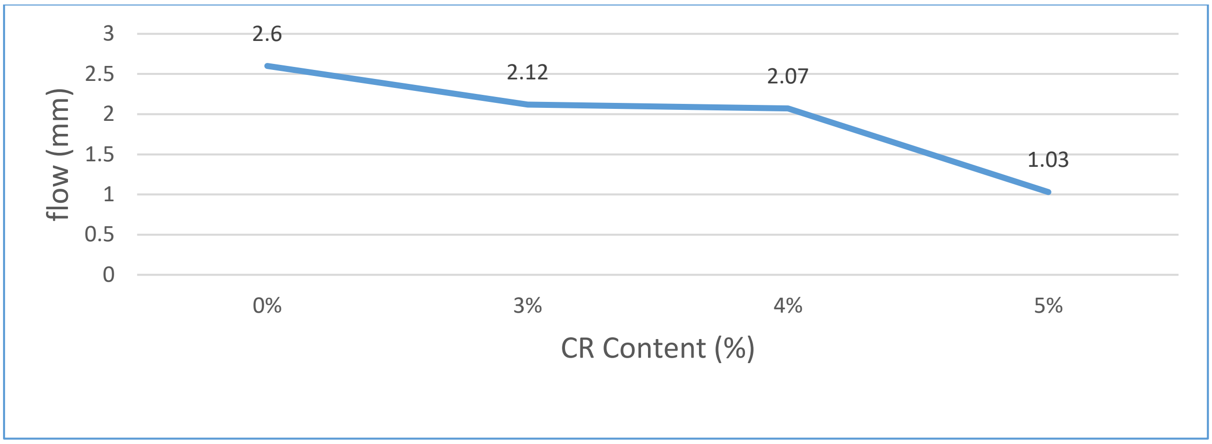

Figure (4): Flow for MCM with 40% RCA & Different Percentages of CR by weight of asphalt binder

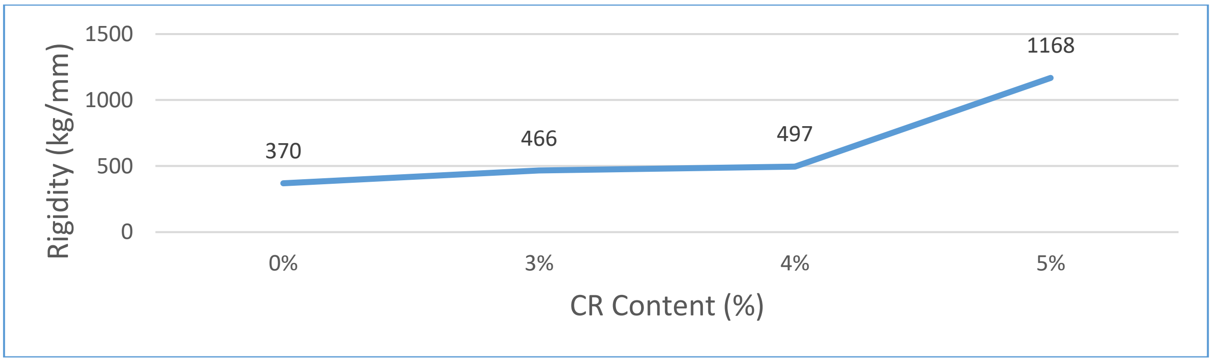

Figure (5): Rigidity for MCM with 40% RCA by weight of aggregate & Different Percentages of CR by weight of asphalt binder

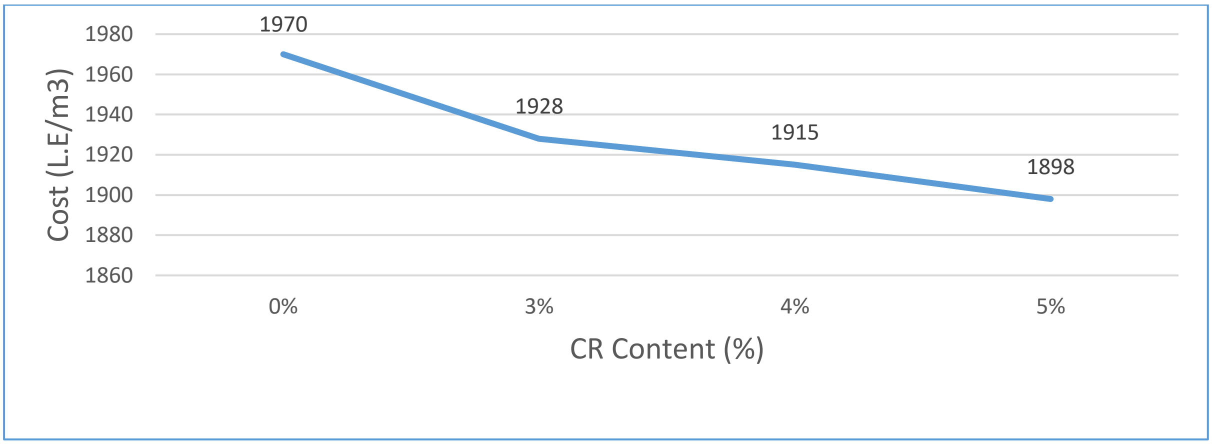

Figure (6): Cost (LE / m3) for MCM with 40% RCA & Different Percentages of CR

The results indicate that by adding crumb rubber with different percentages (3,4, and 5%) by weight of asphalt binder to the modified asphalt mixture with 40% of RCA, as the percentage of CR increased this lead to an increase in stability, decrease in flow, and the mixture's rigidity increased. When adding 5% of crumb rubber, the flow of the mixture decreases to reach 1.03 mm, and the rigidity increases to reach 1168 kg/mm. These values of flow and rigidity are not permissible and result in an asphalt mixture that is not workable on-site. Therefore, the MCM with 4% rubber content & 40% RCA has been chosen to achieve the highest stability with permissible flow and hardness values, while also minimizing the cost per cubic meter of the asphalt mixture.

6.3 Limits of Marshall stability and flow Values

For heavy traffic conditions, the minimum requirement for the Marshall Stability value is 910 kg, indicating the desired strength and stability of the asphalt mix. The minimum acceptable value for Marshall Stability is set at 340 kg, ensuring a certain level of structural integrity. In terms of flow characteristics, the minimum acceptable value for Marshall Flow is either 2 mm units or 0.25 mm units, depending on the specific requirement. These values represent the maximum allowable flow or deformation of the asphalt mix under load. Additionally, the acceptable range for the percentage of air voids in the mix typically falls between 3% and 5%. This range ensures an appropriate balance between density and flexibility in the asphalt pavement, contributing to its overall performance and durability.

6.4 Indirect tensile strength (ITS) test results

The indirect tensile strength ratio (ITSR) % is determined through the following equation.

$$\text{ITSR}(\%) = \frac{\text{ITSR wet (MPa)}}{\text{ITSR dry (MPa)}} * 100$$

The results obtained from this test and ITSR (%) are shown in Table (12).

Table (12): Shows ITS Test Results and ITSR (%) for MCM containing 40% RCA with 0% and 4% CR

Mixture	ITS – dry (MPa)	ITS – Wet (MPa)	ITSR (%)
MCM (0 % CR with 40 % RCA)	**0.783**	**0.637**	**81.35**
MCM (with 4 % CR & 40 % RCA)	**0.853**	**0.711**	**83.35**

The value of ITSR (%) for the modified mix containing 4% CR & 40% of RCA achieve the local and international specification requirements. Figure (7) shows the percentage of indirect tensile strength ratio ITSR (%) for the modified control mix with 40% of RCA, and the modified control mix with 40% RCA & 4% crumb rubber.

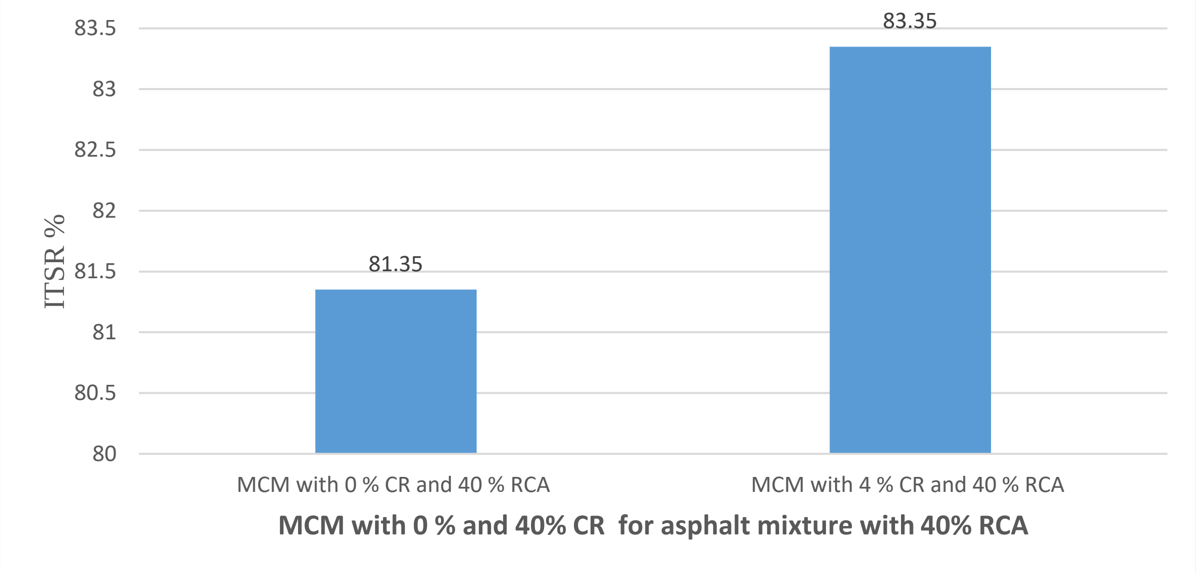

Figure (7): Percentage of Indirect Tensile Strength Ratio ITSR (%) for MCM with 40% RCA and MCM with 40% RCA & 4 % CR

6.5 Loss of stability test results

The results of this test are presented in Table (13). For the MCM with 40% RCA, the stability of dry specimens was 965 kg, while the stability of specimens immersed in a water bath at 60°C for 24 hours was 824 kg. As for the MCM with 4% CR & 40% RCA, the stability of dry specimens was 1030 kg, and the stability of specimens immersed in the water bath was 790 kg. Furthermore, it is observed that the value of the loss of stability is higher in MCM with 40% RCA & 4% CR (23.31%) compared to MCM with 40% RCA only (14.61%). This indicates a reduction in the durability of the asphalt mix and highlights the recommendation of using waste engine oil as a means to improve the durability of asphalt paving.

Table (13): Shows Loss of Stability Test Results for different MCM asphalt mixtures

Mixture	Stability-dry (kg)	Stability-wet (kg)	Stability loss (%)
MCM with 40% RCA	**965**	**824**	**14.61**
MCM with 40% RCA & 4% CR	**1030**	**790**	**23.31**

6.6 Permanent deformation test (Rutting test) results

Figure (8) displays the creep test results, which measures the deflection (ΔH) as an indicator of the resistance to permanent deformation for two types of hot asphalt mixes: MCM with 40% CRA and MCM with 40% RCA & 4% CR. Observing the figure, it is evident that the deflection value for both mixes increases over time, although at a decreasing rate. At the end of the test duration, the deflection values are recorded as 0.28 mm for MCM with 40% RCA and 0.23 mm for MCM with 40% RCA & 4% CR. Based on these results, it can be concluded that MCM with 40% RCA & 4% crumb rubber exhibits a lower deflection value compared to MCM with 40% RCA alone. This suggests that MCM with 40% RCA & 4% CR is expected to have better resistance against permanent deformation, or rutting, compared to MCM with 40% RCA without the addition of CR. The results of the permanent deformation test, specifically the deflection values over time, are illustrated in Figure (8) for MCM with 40% RCA and MCM with 40% RCA & 4% CR.

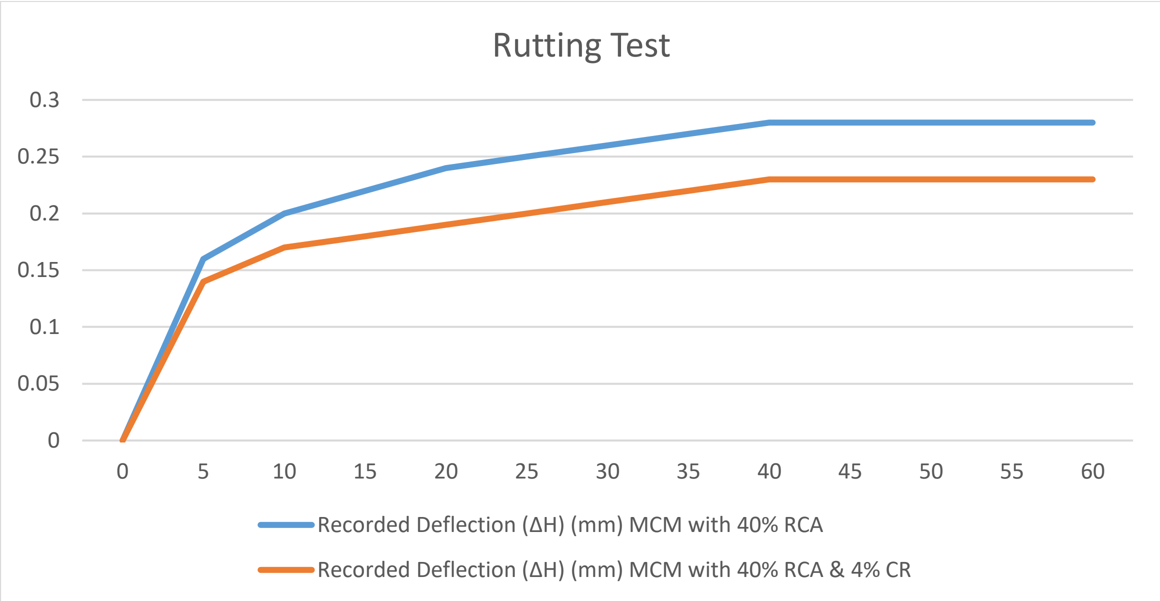

Figure (8): Permanent Deformation Test (Rutting Test) Results (Deflection versus time) for MCM with 40% RCA and MCM with 40%RCA & 4% CR

6.7 Fatigue test results

The tensile strength (σt) of two mixtures, one with 40% RCA and the other with 40% RCA and 4% CR, was estimated using the average failure loads of three specimens from each mixture. The tensile strength (kg/cm2) was calculated using Equation (1), which takes into account the collapse load (P) in (kg), sample radius (b) in (cm), sample height (H) in (cm), and steel punch radius (a) in (cm). Figure (9) shows the tensile strength values of the mixtures with different percentages of CR (3%, 4%, and 5%) at a temperature of 20°C.

$$\sigma t = P / \pi (1.2bH - a 2) \quad \text{----------- Equation (1)}$$

The results demonstrate an increase in the tensile strength of the asphalt mixture when varying ratios of CR are incorporated. This indicates that MCM with 40% RCA & 4% CR exhibits greater resistance to fatigue cracking compared to MCM with 40% RCA alone.

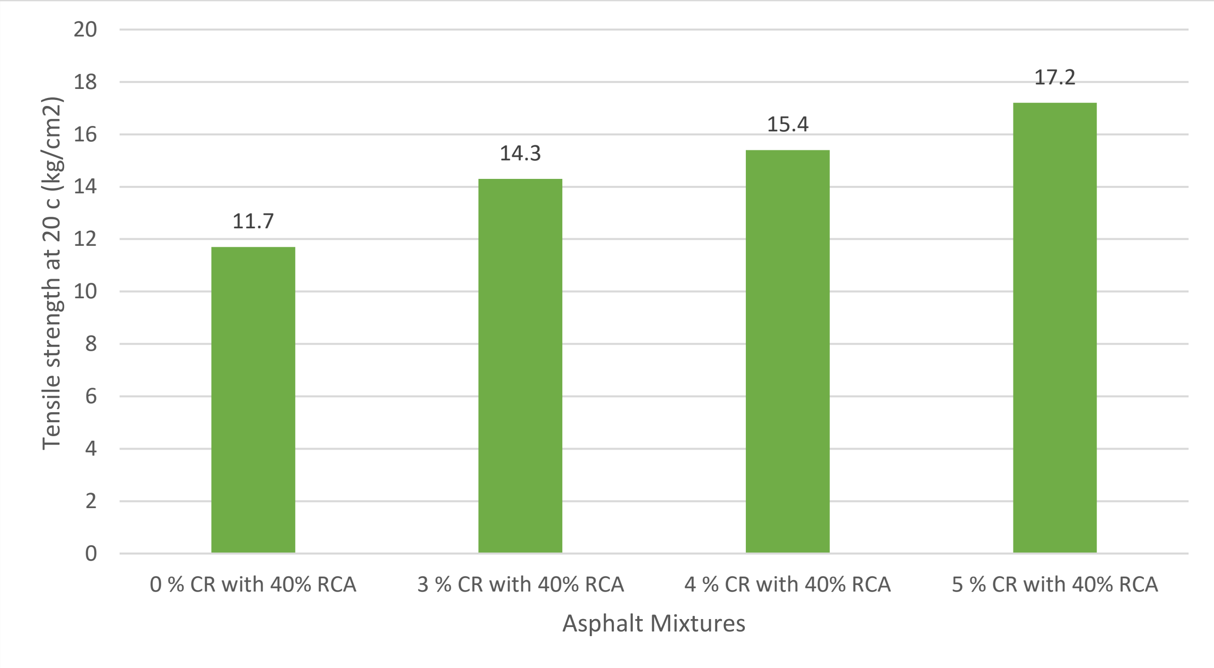

Figure (9): The tensile strength at 20 C as indicator for asphalt mixture's fatigue

6.8 Adding waste engine oil to improve the durability of the mixture

The results of Marshall stability and flow tests versus MCM WITH 40% RCA, 4% CR, and different percentages of WEO (3,4, and 5% of WEO by total weight of asphalt binder) indicate that modified asphalt mixture containing 3 % of waste engine oil increase the flow of the mixture. This means the improving of mix flow (3.17 mm). In the same time, stability and rigidity of the mixture within the allowable limits.
Otherwise, test is performed on the modified asphalt mixture containing 3 % of waste engine oil to compare the results with that without WEO content. Six samples for mixture with 3% WEO by total weight of asphalt binder. were tested. Three dry specimens of MCM with 3% WEO, 4% CR, and 40% RCA were tested. Then, three wet specimens which have been immersed in water bath at 60oC for 24 hours were tested. The average stability for dry specimens was 945 kg. Otherwise, the average stability of wet samples was 844 kg. The loss of stability for the asphalt mixture was (10.71%). This means the improving for durability of the mixture and emphasis the recommendation of using the mix of MCM with 40% RCA, 4% CR, and 3% WEO in asphalt paving. Figure (10) shows the loss of stability (%) for different asphalt mixtures.

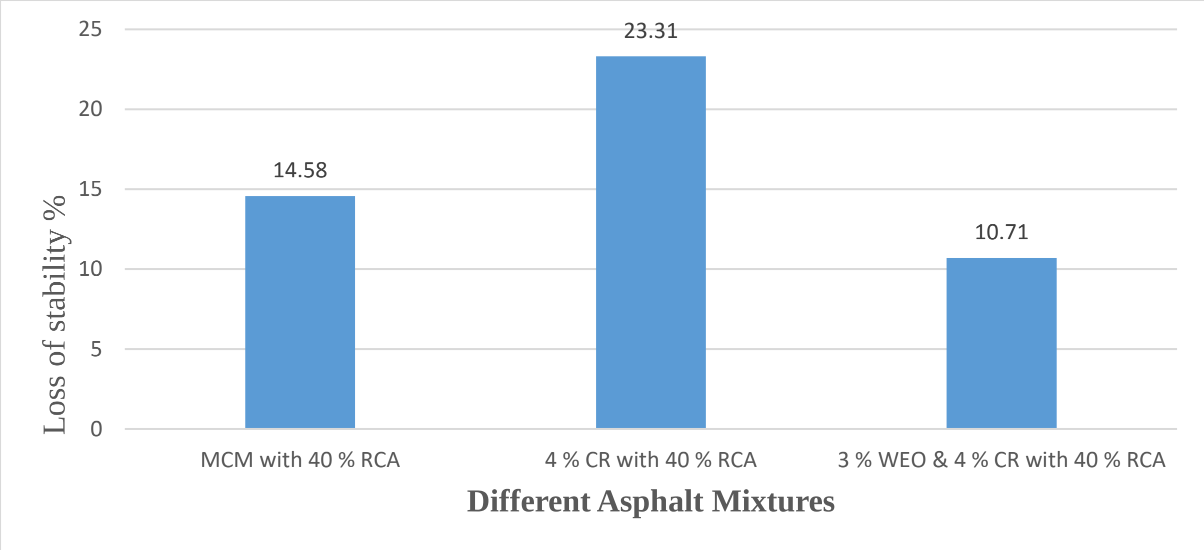

Figure (10): Shows the results of loss of stability (%) for the different mixtures

7. CONCLUSION

This research focuses on studying the impact of various percentages (3%, 4%, and 5%) of CR, by weight of bitumen, in a modified asphalt mixture containing 40% of recycled concrete aggregate in replacement of natural aggregate using the wet process technique. Additionally, the study investigates the effect of different percentages (3%, 4%, and 5%) of WEO by weight of bitumen on the loss of stability percentage of the modified asphalt mixture. A comparative evaluation is conducted to assess the performance of these different CR and WEO percentages compared to conventional asphalt mixtures and the modified asphalt mixture containing 40% of RCA only.

Based on the results of laboratory investigation, the conclusions of this research are presented below:

1. In Marshall mix design, high CR content in modified control mix with 40% RCA tend to have a higher stability and a lower flow than MCM with 40% RCA resulting in improving volumetric resistance.

2. The use of crumb rubber in asphalt mixtures has considerations. CR modified asphalt mixtures require less asphalt content. However, reducing the asphalt content can lead to increased air voids in the mixture, resulting in higher permeability. This increased permeability can negatively impact the durability of the asphalt mixture. Therefore, it is crucial to prioritize the durability of modified asphalt mixtures by using crumb rubber despite the lower asphalt content.

3. The utilization of crumb rubber in asphalt mixtures offers several benefits. By incorporating crumb rubber into bituminous mixes, it becomes possible to address the issue of accumulating scrap tires in landfills. Furthermore, this practice has the potential to improve the long-term performance of pavements. This suggests that utilizing crumb rubber can be an effective method for improving the overall performance and sustainability of asphalt pavements taking into account adding of WEO to the modified asphalt mixture.

4. MCM with 4 % CR & 40% RCA achieves the lowest deflection value, and the highest tensile strength as compared to the modified asphalt mixture without CR. it anticipated

to resist the permanent deformation and fatigue cracking more than MCM with 40% RCA.

5. The addition of 3% of waste engine oil to MCM with 40% RCA & 4% CR tends to increase the durability of the asphalt mixture.

6. Finally, using of MCM with 40% RCA, 4% CR, and 3% WEO enhance the performance of the developed asphalt pavement mixtures.

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Abbreviations and Acronyms

HMA	**Hot Mix Asphalt**
CM	**Control Mix**
MCM	**Modified Control Mix**
RCA	**Recycled concrete aggregate**
SG	**Specific Gravity**
CDW	**Construction and Demolition Waste**
CR	**Crumb rubber**
WEO	**Waste engine oil**