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The Influence of Waste Cooking Oil on Recycled Asphalt Mixture Properties

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Abstract

This study investigated the use of waste cooking oil (WCO) as a potential rejuvenator to find the best dosage and assess its effects on recycled asphalt pavement (RAP), which is essential for more sustainable and environmentally friendly road construction. When added to new asphalt mixtures, RAP reduces the requirement for virgin raw materials, minimizes waste from the removal of old pavements, and lowers the energy required for extraction and refinement. Despite these advantages, the high stiffness of RAP mixtures often restricts their use to less than 30%. This restriction can be mitigated by the use of rejuvenating chemicals. However, due to the greater stiffness of the RAP binder, high-RAP mixes are more likely to break at low temperatures and have poor mixture workability. One of the additives used to address these shortcomings is recycling agents. Mixtures of 25%, 50%, and 75% RAP with 2%, 4%, 6%, and 8% WCO concentrations were critically examined to establish a reliable evaluation of performance. The results demonstrated that RAP is suitable for use in hot mix asphalt, with the optimal WCO range being between 2% and 8%. Overall, the findings demonstrate that combining high RAP proportions with WCO is a viable and sustainable approach to modern road construction.

Keywords: Hot mix asphalt, reclaimed asphalt pavement, rejuvenator, waste cooking oil.

1.Introduction

The amount of trash generated has grown in tandem with the ongoing improvement in life style. Recent data indicate that China produces around 7.5 million tons of waste cooking oil (WCO) eeach year [1]. It is evident that our nation produces a very large amount of waste oil each year, and poor recycling methods might seriously endanger the environment. The fact that one tone of waste oil can contaminate up to one million tons of drinking water highlights how severe this issue is. Waste cooking oil (WCO) is now mostly used in China to make paint, soap, and other chemical goods. At the same time, the amount of traffic on the roadways is steadily rising due to the nation's ongoing transportation sector growth. Problems, including dual carriageways, heavy vehicle proliferation, overloading, and excessive axle loads, are more prevalent than ever. Resurfacing is therefore frequently used as the principal maintenance option when substantial degradation develops in the pavement layers. While this conventional approach incurs significant costs, it also produces considerable waste. These difficulties have prompted academics to investigate novel materials and cutting-edge methods for enhancing pavement performance and encouraging more environmentally friendly road infrastructure practices [2, 3]. According to statistical estimates, the government now extracts more than 10 million tonnes of asphalt pavement mixes annually during medium and heavy maintenance projects[4]. Conventional pavement maintenance techniques have also demonstrated significant flaws and disadvantages in recent years as a result of the government's consecutive implementation of reducing emissions and conserving energy, and environmental protection programs. Relevant workers have conducted extensive research on the use of RAP because it is no longer satisfy the performance and sustainability requirements of modern highway asphalt pavement construction within the prevailing environmental protection framework [5].

Numerous local and international studies on waste oil recycled asphalt mixes have been conducted, combining the drawbacks of a single waste oil treatment technology with the massive volume of road waste. According to the pertinent literature [6, 7], using waste cooking oil can enhance the fundamental performance of waste asphalt mixtures and ageing asphalt. WCO was utilized by Rita Jalkh et al. [8] to revitalize old asphalt on roads. According to the findings of the physical and chemical study, the waste cooking oil caused the aged asphalt's viscosity to rise. WCO may be used as a rejuvenator to allow the old asphalt to be used again as low-grade asphalt. In order to reduce the hardness and brittleness of aged asphalt and enable its effective reuse in new pavement applications, MA Bilema [9] and others employed WCO as an asphalt rejuvenating agent. The findings of the study demonstrate that WCO can be utilized to create an efficient aged asphalt rejuvenator and that it can revitalize old asphalt. The impact of several kinds of asphalt rejuvenators on the functionality of recovered aged asphalt mixtures was investigated by Krcmova Iva et al [10]. The findings of this study demonstrate that these revitalizing substances can restore the qualities of old asphalt. The introduction highlights the overall impact of waste cooking oil on aged asphalt binder, particularly its role as a rejuvenator that helps restore the lost ductility due to ageing. The importance of achieving an appropriate balance between stiffness and brittleness was also emphasized, which is essential to ensure the proper performance of the asphalt mixture by balancing the restoration of ductility and maintaining sufficient stiffness. Therefore, the aim of the introduction was not to provide a comprehensive review of all previous results, but rather to establish the environmental justification and the basic research context of the study, while the more detailed analyses and discussions are presented in the subsequent sections of the research paper.

The efficacy of WCO in restoring reclaimed asphalt pavement (RAP) was evaluated using the Retained Strength Index Test and the Indirect Tensile Strength Test. Examining and analyzing the mechanical properties of asphalt mixtures containing WCO and RAP, as well as determining the optimal dosage and effect of the rejuvenating agent on hot mix asphalt containing RAP, are the objectives of the current study.

2.Materials

The materials employed in this study are readily available locally and are often used in Iraqi road construction. The following materials were used:

2.1 Virgin Asphalt materials

The Karbala facility provided the virgin asphalt binder (VA) utilized in this investigation, which had a penetration grade of 40 to 50. The binder satisfies the national requirements for roads and bridges, as shown by the completion of all required tests in compliance with Iraqi GSRB regulations[11]. Table 1 lists the physical characteristics of the VA.

Table 1. Asphalt Properties.

Characteristic	**Penetration mm/mm at 25 ºC**	**Softening point, ºC**	**Specific gravity at 25 ºC**	**Ductility at 25, cm**	**Flash point, ºC**
Result of the test	46	48	1.032	125	320
ASTM Standard	D5 [12]	D36 [13]	D70 [14]	D113 [15]	D92 [16]
Iraqi specifications for roads and bridges	40-50	-	-	> 100	> 232

2.2 Aggregate

The coarse and fine virgin aggregates came from nearby quarries in Karbala. In accordance with Section R9 of the Iraqi General Specifications for Roads and Bridges [17] , as indicated in Figure 1, the aggregates were sieved, separated, and graded to satisfy the necessary gradation for surface course Type IIIA. The fine aggregate was made up of a blend of natural sand and crushed stone sand, while the coarse aggregate was made up of light-coloured, crushed angular limestone. Natural sand is (< 25%) of the total fine aggregate. Aggregate gradation is shown in Figure 1. The ideal qualities of the asphalt mixture were reached by using the middle limit for gradation. As shown in Tables 2 and 3, physical characteristics were assessed in Kerbala University's highway laboratory.

Table 2. Physical Characteristics of Virgin Fine Aggregate

Characteristic	ASTM Standard	Result
Bulk specific gravity, gm/cm^3	C128 [18]	2.550
Apparent Density (g/cm³)	C128 [18]	2.736
Water absorption, %	C128 [18]	2.670
Clay lumps, %	C142 [19]	3

Table 3. Physical Characteristics of Virgin Coarse Aggregate

Characteristic	ASTM Standard	Result	SCRB Standard for Surface Course
Bulk specific gravity, gm/cm^3	C127 [20]	2.63	-
Apparent specific gravity, gm/cm^3	C127 [20]	2.66	-
Bulk SSD specific gravity, gm/cm^3	C127 [20]	2.614	-
percentage of Los Angeles abrasion wear,	C131 [21]	21	35%
Water absorption, %	C127 [20]	0.605	-
Clay lumps, %	C142 [22]	0.081	-

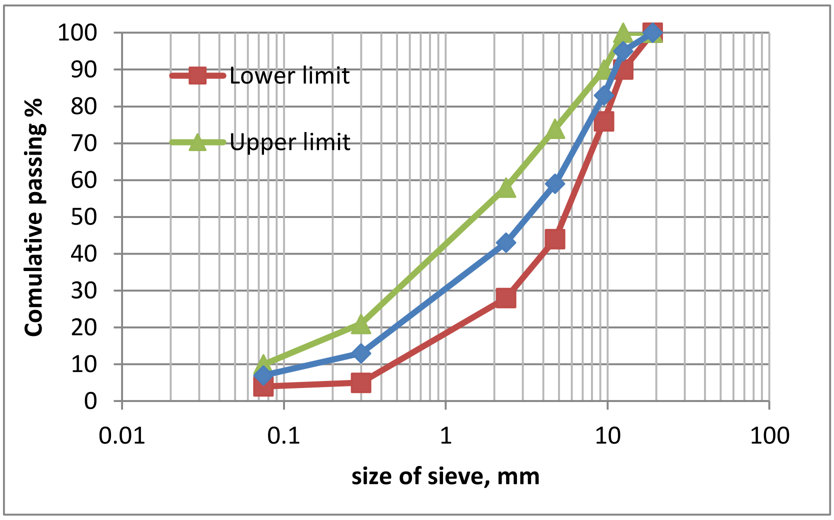

Figure 1. Surface Course Gradation As stated by SCRB[11].

2.3 Recycled Materials

In this study, the following recycled materials were employed:

2.3.1 Reclaimed asphalt pavement (RAP)

As shown in Figure 2, the recovered asphalt was collected from the road that connected Baghdad and Kerbala after the pavement had degraded with many cracks and potholes. It’s important to note that the pavement that was at least ten years old, guaranteeing that the asphalt binder had experienced oxidation and long-term aging, which is in line with the goals of this investigation. The milling operation reached a depth of 10 cm. When the RAP component in a hot asphalt mixture is 25% or greater, the bitumen in the RAP must be considered [23]. In this study, recycled asphalt ratios of 25%, 50%, and 75% were determined to represent low, medium, and high levels of aged asphalt binder، in order to study the effect of waste cooking oil under different ageing conditions. The ratios of 25%, 50%, and 75% RAP were used, in addition to doses of waste cooking oil, based on previous studies. These ratios were chosen to evaluate the impact of increasing the proportion of recycled materials on the performance of the mixture while maintaining compatibility between the mentioned doses. A crucial step in the design of recycled HMA is evaluating the properties of RAP, with bitumen content and aggregate gradation being crucial requirements. Three samples were chosen at random from the RAP stockpile in order to achieve this, and an extraction test conducted in accordance with ASTM criteria was used to separate the binder from the aggregates, and its gradation is shown in Figure 3. Several important characteristics are included in the suggested Marshall test indices for asphalt surface courses, as per ASTM, AASHTO, and the majority of highway requirements. These include the bulk density, which is stated in grammes per cubic centimetre (g/cm^2), the flow value, which is measured in millimetres (mm), the proportion of air voids, and the stability of the RAP mixture, which is given in kilonewtons (kN). Additionally, the calculation of the binder content after extraction, represented as a percentage, takes into account the qualities of the binder asphalt.

Figure 2. Location of RAP

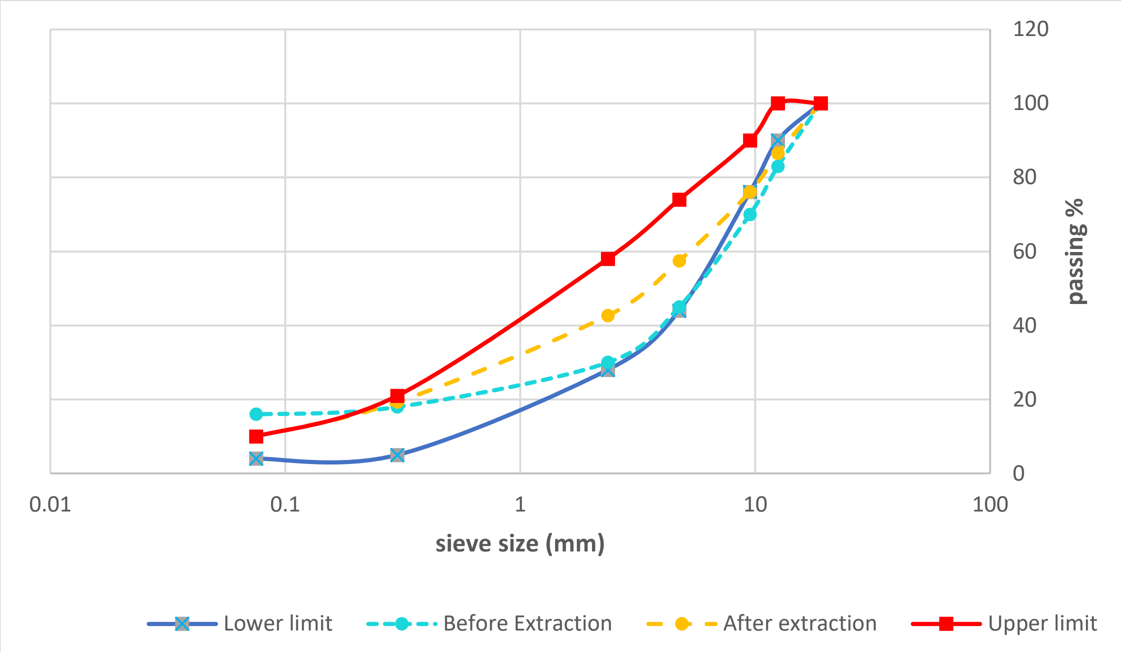

Figure 3. gradation of RAP aggregate test.

2.4 The Waste cooking oil (WCO)

Waste cooking oil (WCO) is typically generated from cooking and frying processes and can serve as an efficient rejuvenator due to its composition, which resembles that of lighter oil components found [24] in asphalt. Food markets produce enormous amounts of WCO annually; China produces 826 million gallons, the USA produces three million gallons, and other nations produce even more [25]. Around 3 billion gallons of used cooking oil are gathered from US restaurants and fast food chains each year, according to the US Environmental Protection Agency (6) [26].

Driven by environmental concerns and the growing need for sustainable pavement practices, asphalt binders incorporating WCO have gained significant attention in recent years. WCO is typically gathered from recycling facilities, restaurants, food companies, and residential disposal sites [27]. The strain on the environment and public health can be greatly reduced by properly recycling WCO in pavement [28]. Since WCO is often cooked at high temperatures, it contains few volatile ingredients, such as harmful fumes, when reheated [29]. Furthermore, WCO is safe to use since its flash point is usually greater than the temperatures required for the manufacturing and compaction of asphalt mixtures [30]. WCO can be used straight to virgin petroleum asphalts as a rejuvenator or modifier for old binders. In asphalt binders, the use of WCO or WCO-based bio-oil has typically been shown to: (a) lower the softening point and viscosity while promoting higher penetration and ductility [24, 29]; (b) increase phase angle and decrease dynamic modulus, reflecting decreased deformation tolerance and limited elastic rebound capability [31]; and (c) enhance intermediate and low cracking resistance. Table 4, table 5 show the optimum ratio of WCO and physical characteristics of WCO respectively. Noting that waste cooking oil was obtained from one of the restaurants in Karbala, specifically from Ahmed Al-Abdullah fast food on Al-Sanater Street.

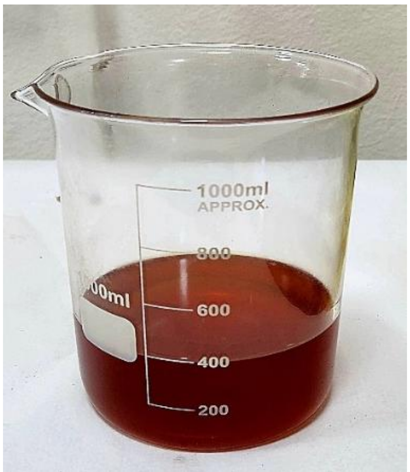

Figure 4. Waste cooking oil.

Table 4. Optimal dosage of WCO.

RAP Content	The Optimal dosage of WCO
25%	4%
50%	2%
75%	8%

Table 5. Physical Properties of Waste Cooking Oil (WCO)

Test	Results
Relative density (gm/cm^3)	0.93
Viscosity	155
Water content %	0.32

2.5 Methodology of RAP Addition and Regenerated Rejuvenator

- After conducting a sieve analysis of reclaimed asphalt pavement (RAP) from the Karbala–Baghdad Road, weights for each sieve were measured per Iraqi specifications for road surface layers. Virgin hot mix asphalt (HMA) was blended with 25%, 50%, 75%, RAP by total mixture weight, with a Marshall specimen weight of 1200 g. Virgin aggregates were mixed with RAP considering the existing asphalt content, then heated to 165–175°C According to ASTM D6927*[32]* . Heated virgin asphalt binder at 150°C was added to the mixture, which was mixed for no more than 90 seconds to ensure proper coating of the aggregate particles.
- The rejuvenator was mixed with virgin asphalt at 2%, 4%, 6%, and 8% by weight, mixture was heated to 150°C and stirred at 2700 rpm as shown below in Figure 5, for 10 minutes to achieve uniform integration.[33]

Figure 5. Blending mixer.

2.6 Test Methods

2.6.1 Preparation of Marshall Samples

Marshall samples were created depending on the amounts of RAP in order to determine the optimal asphalt concentration for the control mix as well as mixtures with RAP. A total of 60 samples were collected with asphalt concentrations of 4%, 4.5%, 5%, 5.5%, and 6% by specimen weight (1200 g). Results showed that optimal asphalt content for the reference mixture was 4.9%. As seen in Figure 6, thirty-six Marshall samples were created once the optimal asphalt content was established in order to determine the optimal WCO proportion for mixes incorporating RAP.

While combinations with 50% and 75% RAP required an optimal level of 5.5%, the mixture with 25% RAP required an ideal value of 5%. WCO was added to the mixes at a rate of 4% of asphalt weight for 25% RAP, 2% for 50% RAP, and 8% for 75% RAP based on the following WCO ratios. After the optimal asphalt and WCO contents were established, a total of 48 samples were produced for indirect tensile strength testing and Retained Strength Ratio (RSR) (IRS). All samples were prepared in accordance with ASTM regulations [34]. Each specimen was compressed with 75 blows per face using a Marshall hammer to achieve 4% air gaps. The fabricated specimens are presented in Figure 6. The optimal asphalt content and the proportions of waste cooking oil were determined by conducting a Marshall stability test as shown in Figure 7 and Figure 8.

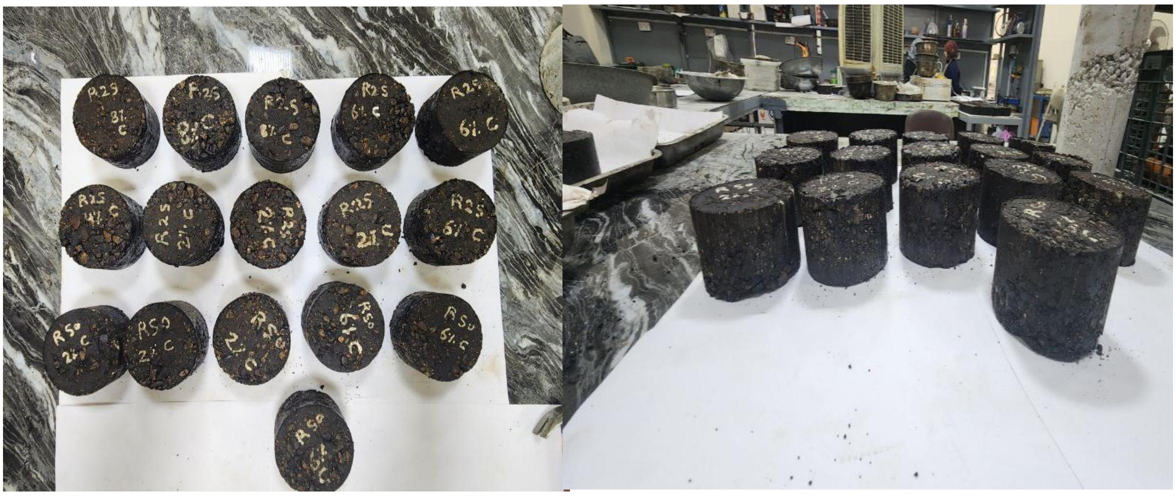

Figure 6. Marshall test specimens.

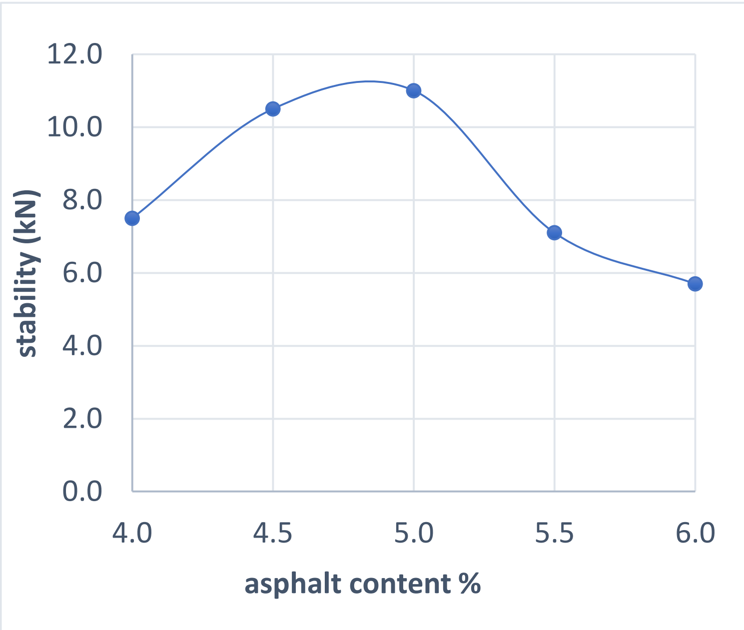

Figure 7. Marshall Test Result for O.A.C.

As seen in Figure 8, Interpretation of determining the optimal ratios of waste cooking oil at different percent of RAP content, where at (R25%+4%wco) The mixture recorded the highest stability value at this relatively low RAP content. The amount of aged binder added to the mixture is limited, but this binder still contributes to increasing the stiffness compared to the reference mixture. Therefore, a higher percentage of WCO is needed to sufficiently soften the aged binder, restore its ductility, and improve its workability. Conversely, when the RAP content is increased to 50% with 2% WCO, the mixture still shows high stability despite the reduced WCO percentage. This is because the mixture already contains a significantly higher percentage of aged oxidised binder, which in turn increases the stiffness of the mixture. Since using a higher percentage of WCO at this RAP content may excessively soften the binder, weaken the interlocking between the aggregates, and reduce stability due to the loss of internal resistance.

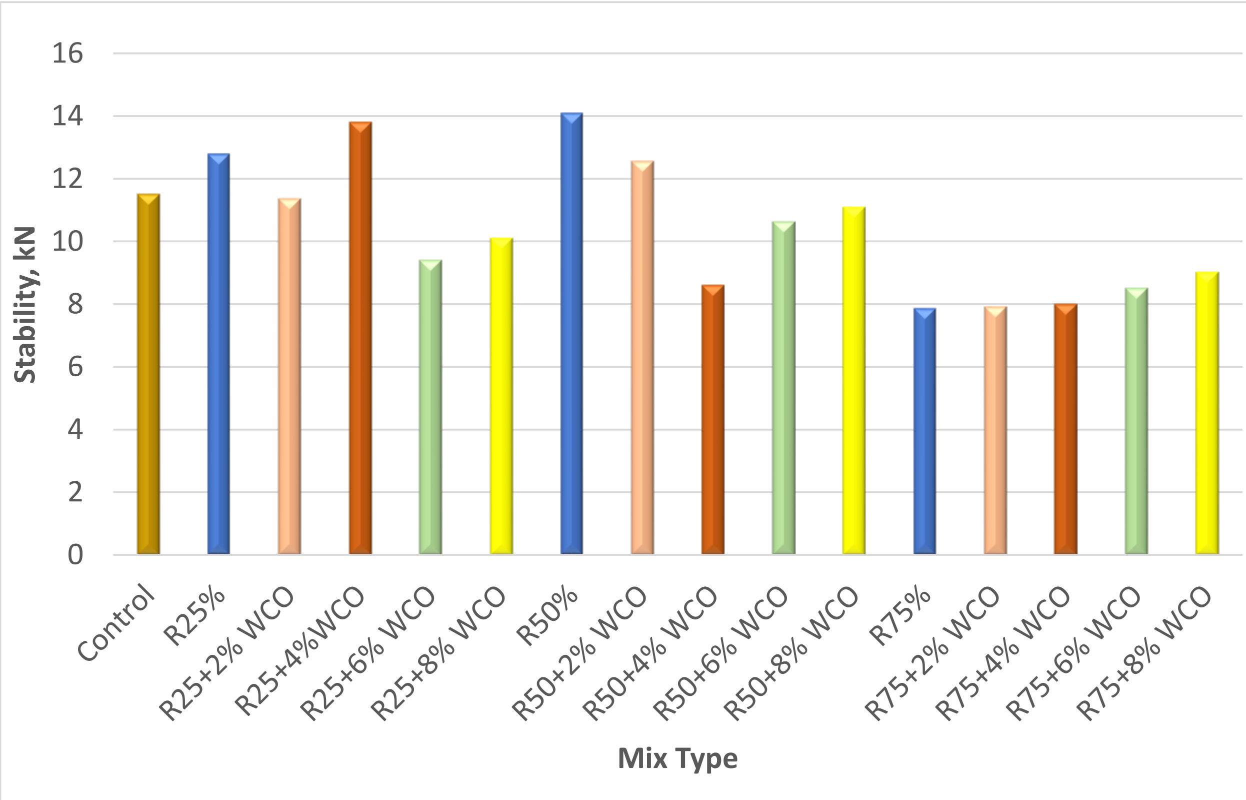

Figure 8. Effect of RAP Content and WCO Content on Marshall Stability Results.

2.6.2 Indirect Tensile Strength (ITS)

The objective of this experimental technique is to evaluate the cracking susceptibility of asphalt mixes. The Indirect Tensile Strength (ITS) test is among the most effective methods for determining asphalt's tensile strength under stress. This test evaluates the specimen's resistance to cracking and is carried out in accordance with ASTM [20] criteria. The materials were compacted using a Marshall Hammer, and three specimens were kept in a controlled dry environment maintained at 25 °C, and the testing apparatus is shown in Figure 9. The following formula was used to calculate the indirect tensile strength:

$$ITS = 2000\, P/\pi D t \qquad (1)$$

ITS=Indirect tensile strength, kPa

P = maximum load, N

t= height of the specimen right before the test, mm

D= diameter of the specimen, mm.

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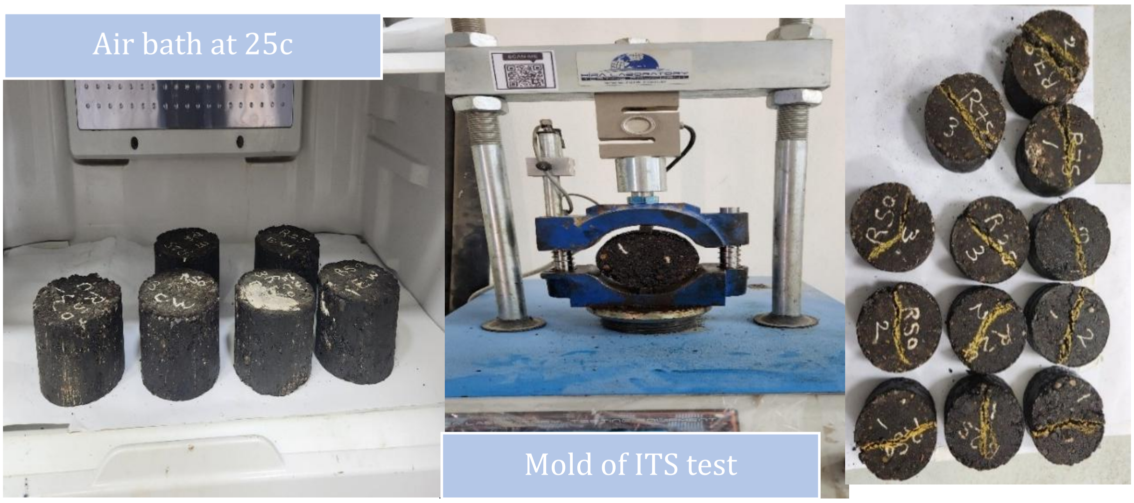

Figure 9. ITS test Conditioning: 2 h at 25 °C (Air Bath) [35].

2.6.3 Tensile Strength Ratio Test

Aim of this testing process is finding of such a test is the moisture susceptibility of asphalt mixtures. It evaluates the impact of water on the tensile strength of compacted bituminous mixes, including asphalt cement. Figure 10 shows the Moisture Susceptibility Index / Indirect Tensile Strength Ratio (TSR or IRS) test parameters in accordance with AASHTO T283 (or ASTM D4867) by contrasting the tensile strength of companion specimens immersed in water under particular circumstances with that of freshly molded and cured specimens. The procedure produces a numerical index of retained strength. The following formula is used to calculate. The Retained Strength Index (TSR):

$$TSR\ \% = (ITS2/ITS1) \times 100 \qquad (2)$$

TSR %= tensile strength ratio

ITS1= the dried specimens' ITS value.

ITS2= the moist specimens' ITS value.

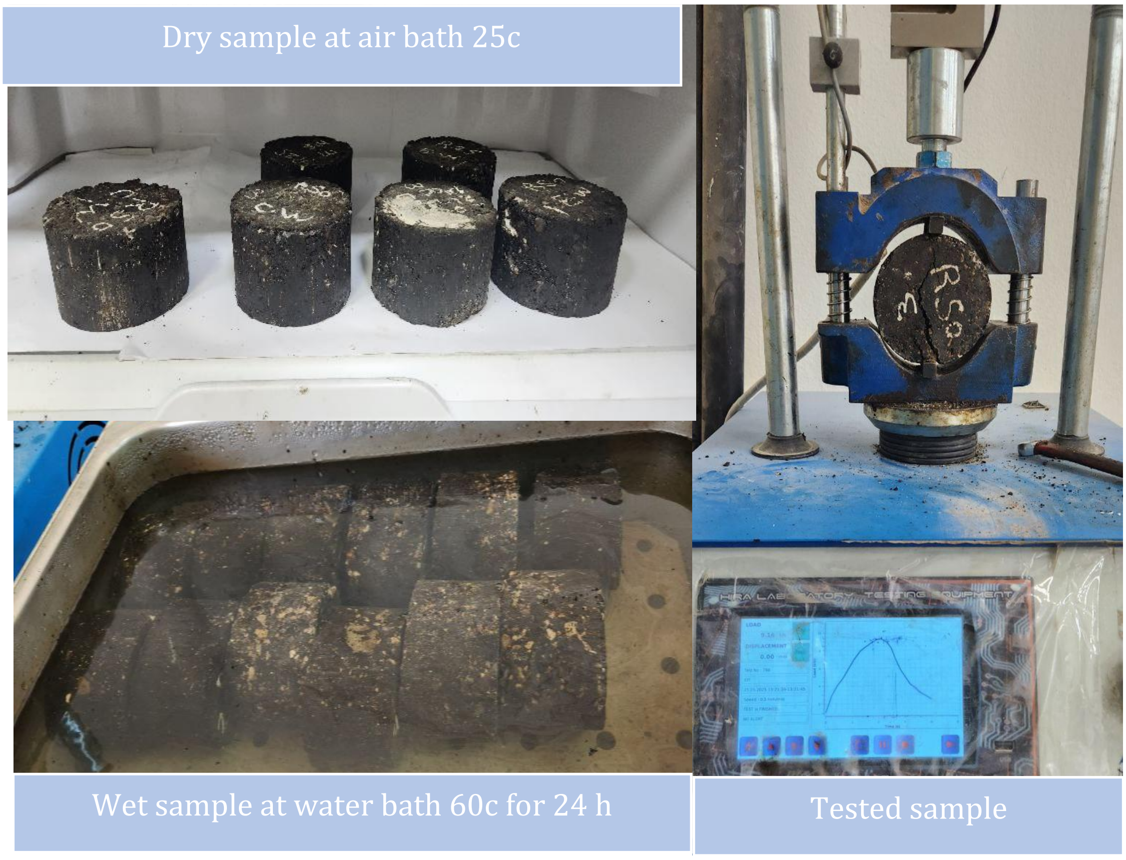

Figure 10. Sample at the ITS device. Curing at 60 °C for 24 hours in a water bath before test[36].

4. Results and Discussion

4.1 Marshall Test Results

Each mix satisfies the minimum stability requirement of 8 kN for heavy-traffic highways, as well as the bulk density and air void requirements. Values fall within the acceptable Marshall Flow range of 2–4 mm. As a result, the RAP mixtures performs better than the control mixture. RAP includes an asphalt binder that has oxidised over time. Consequently, the aged binder is frequently stiffer and more resistant to deformation than the new binder. Adding RAP increases the asphalt's overall strength and stability. Where high stability values are associated with the hardened binder. However, the inclusion of waste cooking oil had a supplementary effect that increased the aged binder's homogeneity, coating capacity, and hardness. The aged binder and the modification process that the waste cooking oil provides work together to provide the high stability values. Figures 11 and 12 show the results of the flow and stability tests. A noticeable drop was observed when 75% RAP was added, indicating that a large amount of recycled material may cause the asphalt mixture to lose some of its cohesiveness and flexibility due to the aged asphalt binder's increased stiffness. It should be mentioned that each mix type has had three samples tested.

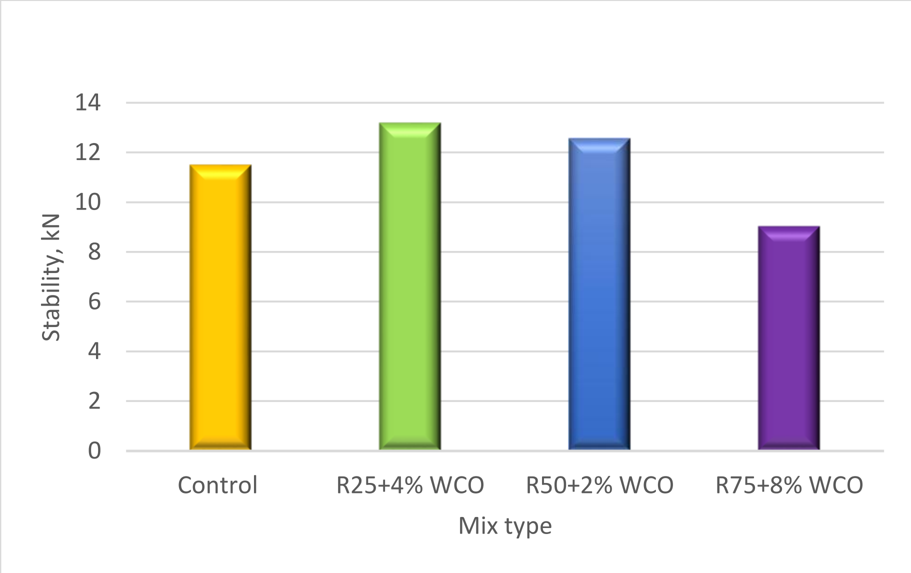

Figure 11. Values of Marshall stability.

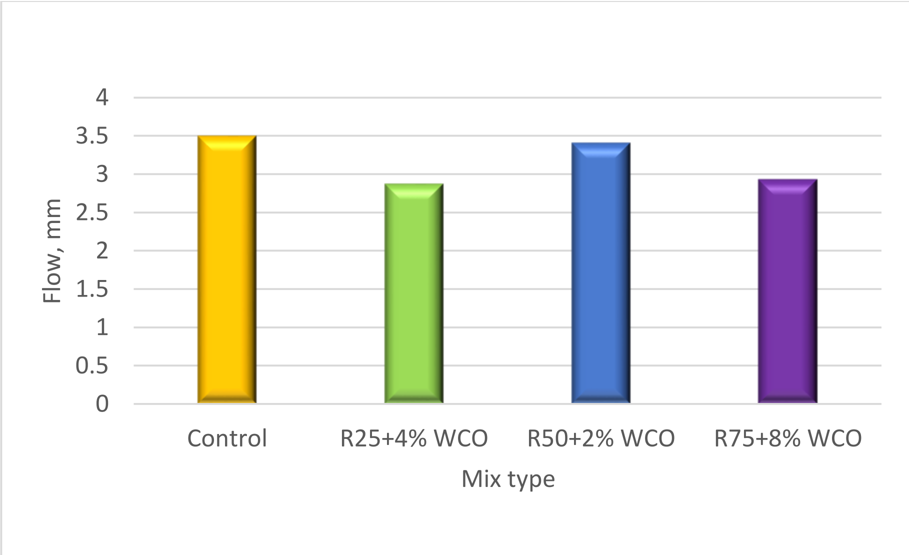

Figure 12. Marshall flow values.

4.2 Indirect Tensile Strength Test Results

The indirect tensile strength (ITS) test performed to evaluate the tensile behaviour of hot mix asphalt mixtures, which is directly related to the pavement's resistance to cracking. Figure 13 illustrates the ITS results for the mixtures incorporating RAP.

The findings indicate that a greater RAP content improves the performance of the asphalt mixture. Up to, the maximum ITS measure, Figure 13 shows how increasing the RAP percentage increased the ITS values in comparison to the control mixture. However, as the RAP percentage reaches 75%, the ITS begins to decline. The addition of RAP in the mixture is what caused the increase in ITS levels since it contains aged asphalt binder that has oxidised gradually over the course of time. Because this aged binder is often stiffer and more resilient to deformation than the fresh binder, the mix's overall strength and stiffness are raised, this test did not aim to directly describe the behaviour of crack initiation or propagation, but rather to provide a comparative assessment of how the used oils and the binder affect the performance of the mixture. Furthermore, the use of WCO may act as a rejuvenator by softening the aged binder in RAP and potentially enhancing its coating ability on aggregates. This rejuvenation process enables the binder to regain its flexibility, reducing its vulnerability to cracking, which leads to higher ITS values. When working with difficult mixtures, a higher tensile strength at failure is seen to be advantageous. It should be mentioned that each mix type has been tested on three specimens. Since the high ITS values are due to the combined effect of the hardened bond in the RAP and the modification process provided by waste cooking oil.

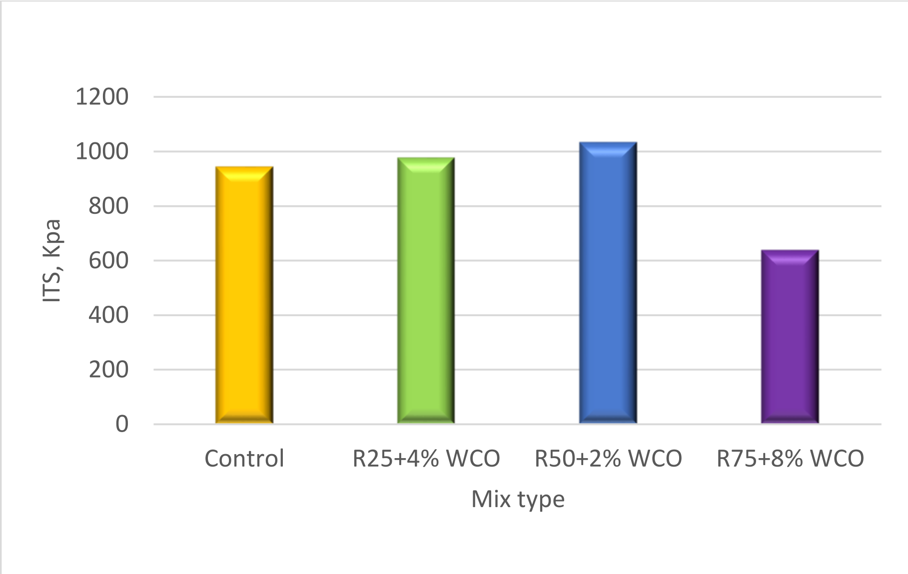

Figure 13. Measured ITS values at a test temperature of 25°C.

4.3 Tensile Strength Ratio (TSR) Results

Although recycled mixes (RAP + WCO) still attained values greater than the reference mixture, their resistance to moisture damage declined as the RAP content increased to 50% and 75%. However, the mixtures still exhibited satisfactory performance when evaluated for moisture resistance. (TSR) findings. Over all, Waste cooking oil interacts with the aged binder by compensating for the light components lost during oxidative ageing, reducing asphaltene agglomeration, and lowering the binder's viscosity. This interaction helps improve the mobility of the binder and restore its ductility, while reducing excessive brittleness and stiffness. These additives have enhanced the mechanochemical interpretation of the results, while reducing hypothetical interpretations, by directly linking the observed performance of the asphalt mixtures to the rejuvenating effect of used cooking oil on the aged asphalt binder. As seen in Figure 14, the recycled combinations performed better overall than the reference mixture. It should be noted that for every mix type, three samples have been evaluated.

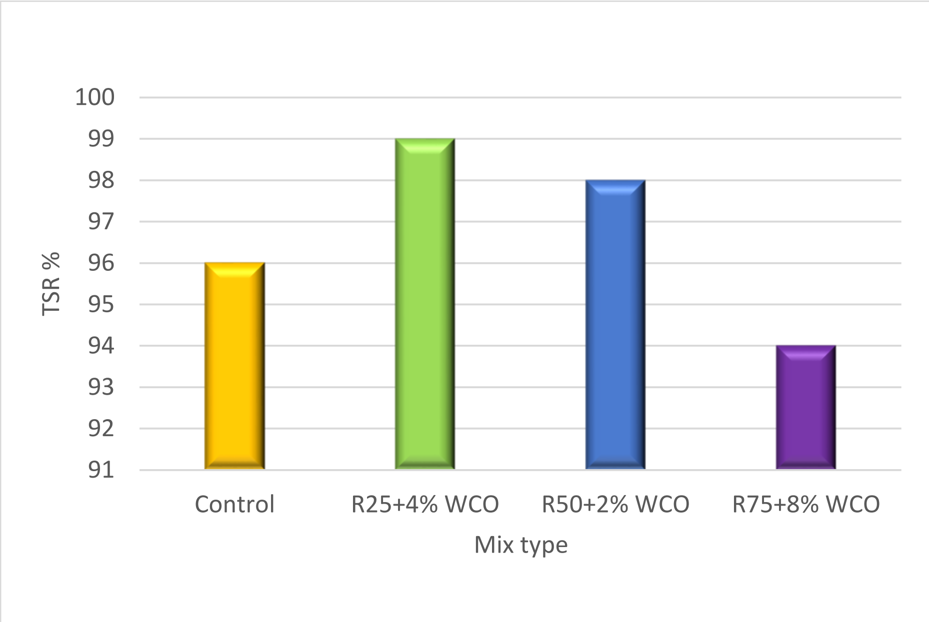

Figure 14. Results of tensile strength test (TSR).

5. Conclusions

The main key point of this study is the ability of using WCO as a renewing agent to revive ageing asphalt and its mixture. To find the discrepancies, different volumes of waste oil have undergone joint physical performance testing. The following conclusions are drawn from the investigation's findings:

1. The study demonstrated that producing asphalt mixes with a high RAP percentage while still adhering to hot mix asphalt criteria is feasible.
2. Asphalt mixes incorporating 25% and 50% RAP, coupled with 4% and 2% waste cooking oil, had higher stability than the virgin mix. The stability values increased by 14.6% and 9.2%, respectively, for the combinations that comprised 25% and 50% RAP with waste cooking oil.
3. All flow values fall within the range of specification; however, as the RAP content increased, the flow rate progressively dropped.
4. The results indicate that the mixtures had increased resistance to moisture damage.
5. As seen by TSR values over 80%, the absolute minimum needed by standard requirements, TSR values were higher in blends containing regenerated RAP than in the reference -mixture.
6. Impact of waste cooking oil was to improve the hardness, coating capacity, and homogeneity of the aged binder. These values are the result of a combination of the aged binder and the modification process that the waste cooking oil offers. This will make a well-compacted mixture by decreasing air gaps and restoring asphalt properties. These actions all help to improve moisture resistance.

Declaration of generative AI and AI-assisted technologies in the writing process

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Disclosures

The authors have no conflicts of interest to declare in relation to this manuscript.

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تأثير مخلفات زيت الطهي على خصائص الخلطة الإسفلتية المعاد تدويرها

الخلاصة: تناولت هذه الدراسة استخدام زيت الطهي المستعمل (WCO) كمجدد محتمل بهدف تحديد الجرعة المثلى وتقييم تأثيره على الرصف الاسفلتي المعاد تدويره (RAP)، وهو ما يعد امرا مهما لتحقيق انشاء طرق أكثر استدامة وصديقة للبيئة. عند اضافته الى الخلطات الاسفلتية الجديدة، يسهم ال RAP

في تقليل الحاجة الى المواد البكر الخام، والحد من النفايات الناتجة عن إزالة الأرصفة القديمة، وخفض الطاقة اللازمة لعمليات الاستخراج والتكرير.على الرغم من هذه المزايا، فان الصلابة العالية لخلطات ال RAP غالبا ما تحد من استخدامها الى نسب اقل من 30%. حيث يمكن التخفيف من هذا القيد من خلال استعمال المواد المجددة. ومع ذلك، وبسبب الصلابة العالية لرابط ال RAP، فان الخلطات ذات النسب العالية منه تكون أكثر عرضة للتشقق عند درجات الحرارة المنخفضة، كما تعاني من ضعف قابلية التشغيل.من بين الإضافات المستخدمة لمعالجة هذه المشكلات هي عوامل إعادة التدوير. حيث تم فحص خلطات تحتوي على نسب 25%و50%و75% من ال RAP مع تراكيز 2%و4%و6%و8% من زيت الطهي المستعمل بشكل دقيق من اجل تقديم تقييم موثوق للأداء.أظهرت النتائج ان الRAP مناسب للاستخدام في الخلطات الاسفلتية الساخنة، حيث يتراوح المجال الأمثل لزيت الطهي المستعمل بين 2%و8%. بشكل عام، تبين النتائج ان دمج نسب عالية من الRAP مع زيت الطهي المستعمل يعد نهجا فعالا ومستداما في انشاء الطرق الحديثة.

الكلمات المفتاحية: خلطة اسفلتية حارة، أسفلت معاد تدويره (RAP)، مادة مُجدِّدة، زيت طهي مستعمل.