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Waste Cooking Oil as Sustainable Rejuvenator in Recycled Asphalt Pavement

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Abstract- The practice of disposing of traditional asphalt pavements in Pakistan is harmful to the environment and natural resources. Only 15% of old asphalt material has been recycled on Motorway-2 (M2) near Sheikhupura so far, according to existing guidelines. A study aimed to increase recycled asphalt in Pakistan using waste cooking oil (WCO) as rejuvenator. The asphalt mixture containing 50% recycled materials comprising 3.45% recycled binder was investigated for consensus properties, indirect tensile strength, and rutting resistance using WCO. The results showed that WCO of 9% is best for equating the properties of recycled binder and mixture to neat binder and mixture performance, except for ductility. The improved performance of recycled mixtures was attributed to adequate interlocking in the asphalt mixture due to stimulation and mobility of the recycled binder because of effective use of WCO. The recycled asphalt mixture displayed almost equivalent rut and moisture resistance to virgin asphalt mixture at a WCO of 9%. The long-lasting integrity of the rejuvenator in the recycled asphalt mixture containing WCO allowed it to sustain repeated wheel loads when subjected to wheel tracking test. The study's findings could be useful in recycling old asphalt materials for engineering purposes, utilizing WCO, and indirectly benefiting the environment by reducing pollution generated due to dumping of aged asphalt materials because of demolishing of asphalt roads after their service life.

Keywords- Recycled Asphalt, Marshall Mix Design, WCO, Viscosity, Rutting Resistance

I. INTRODUCTION

The asphalt pavements when reach the end of their service life span, the aged materials such as bitumen and aggregates can still be recycled, called reclaimed or recycled asphalt pavements (RAP) [1]. When bitumen oxidizes as a result of exposure to the environment and traffic, substances known as Saturates, Aromatics, Resins, and Asphaltenes (SARA) are released [2]. The aged bitumen in timeworn asphalt pavements has sufficient stiffness with almost no mobility to be mixed with aggregate and neat binder. Therefore, the aged materials collected from old pavements are used in conjunction with new asphalt materials to produce new asphalt pavements [3]. Asphalt rejuvenators are substances used to bring life back to the aged binder thereby mobilizing the aged bitumen in recycled asphalt, consequently restore saturates, aromatics, resins and asphaltenes (SARA) in aged binder. In order to get long-lived, pollution free and cost effective pavements, the pavement recycled materials should preferably be used to have new asphalt pavements [4]. The asphalt recycling would significantly decline energy consumption, and emission of greenhouse gasses, thereby eliminating the need of landfill disposing. It was also concluded that the recycling of cold asphalt mixtures have more environmental and economic advantages than hot mix asphalt [5]. The recycled materials are required to be reprocessed not only to get cheaper pavements, but also to get rid of environmental pollution as indirect benefit. The asphalt pavements are used worldwide because of low construction and maintenance cost, safety, and easy recycling [6]. More than 260×10^6 tons of Hot Mix Asphalt (HMA) mixture was produced during 2008 and 2017 in Europe every year. Asphalt recycling is the best way to reduce the cost of virgin materials in order to do more with fewer budgets [7]. Over the past three decades, recycled asphalt has been extensively used worldwide not only because of economic and environmental benefits but also to improve the performance of asphalt pavements and make best utilization of the natural resource as well [8-12]. Recently, there has been emphasis on the asphalt recycling strategies due to raising cost of neat binder.

It should be noted that high RAP content represents 25 % or more RAP by weight of HMA in asphalt pavements. About 35 US states allow 29 % RAP to be used in asphalt intermediate layer [13]. RAP contents of 10 % and 40 % were used in conjunction with new asphalt materials where three blending cases, black rock (no blending), 100% blending and actual practice were studied in asphalt recycling which indicated the blending between the RAP binder and virgin binder. It was concluded that the difference among the specified three cases at 10 % RAP is negligible. The difference between the black rock case and the other two cases became significant. However, the difference between the 100 % blending and actual practice was also insignificant. The laboratory performance of HMA containing high RAP content was studied in terms of low- temperature cracking, fatigue performance and elastic modulus. The composite asphalt mixture was found to be more susceptible to low-temperature cracking with a decline in fatigue resistance and rise in elastic modulus [14-15]. The performance of HMA containing 20% RAP and virgin HMA was studied in the laboratory in terms of complex modulus. The difference of the complex modulus for both types of samples was found to be insignificant. But the modulus of HMA containing 40 % RAP was found to be 49% higher than the modulus of virgin mixture [16]. A study focused on the use of WCO as a solution to regenerate waste oil and enhance the self-healing ability of asphalt materials. The capsules synthesized with waste oil were analyzed for their wetting ability, capillary, anti-aging, and self-healing performance. The optimal healing agent was found to be waste rapeseed oil, with superior overall performance. The addition of capsules increased the fatigue life extension rate of aged mixtures by 10-30% and inhibited waste oil leakage, reducing 38% release [17].

Reprocessing WCO effectively contributes to resource conservation, carbon emission reduction, and responsible consumption. The application of WCO solutions in pavement construction is expected to be feasible and economical, especially for lightweight and medium weight block pavements. Further studies are needed to understand its effects on different asphalt block pavements [18]. Rejuvenators offer a number of environmental benefits over other traditional asphalt building materials when used in asphalt recycling. These advantages include strength, durability, and resistance to extreme weather, in addition to resilience to hazards like fire, thermal stress, and local availability [19]. The pavement industry has been searching for workable solutions to preserve a safe environment, improve pavement performance, and safeguard finite natural resources [20]. In order to provide a safe and affordable transit system; it has become necessary in recent years to renovate the current pavement infrastructure. With the price of crude oil rising, recycled asphalt pavement (RAP) is becoming more and more popular as a more affordable option to pure bitumen that occurs naturally. The waste that has an adverse effect on the atmosphere is the waste that is disposed of in landfills without any further processing. Recyclable oils proved to be a cost-effective solution to the problems of natural resource protection and high construction prices. The incorrect WCO disposal is the main contributor to environmental, ecological, and municipal problems. The fifty two (52) locations of fast food restaurants in Trinidad and Tobago alone utilized 409,000 L of oil annually or 151 L each week on average [21-22]. One million litres of clean water are contaminated by one litre of old oil. Third-world countries lag behind when it comes to recycling trash. A US gallon of WCO was retrieved from a South Trinidad restaurant to be studied. According to the results, raising the ultra-clarifying face oil (UFO) dose had the same effect on stiffness reduction, and increasing the elasticity dosage. Table 1 lists various rejuvenators that can breathe new life into worn-out asphalt.

Table I: Commonly Used Rejuvenating Agents (NCAT, 2014) [23].

Practicing Rejuvenators		
Waste Engine Oil Bottoms	Waste Engine Oil	Sylvaroad PR 1000
Waste Vegetable Oil	Waste Vegetable Grease	Brown Grease
Hydrogreen	Storbit	Reclamite
Ergon Hyprene	Hydrolene	Hydrolene

Waste cooking oil can significantly reduce the carbon footprint of asphalt production by reducing the use of virgin materials, lowering energy consumption, and reducing CO_2 emissions. This is achieved by rejuvenating recycled asphalt binders with waste cooking oil, which can improve the mix's workability and long term performance. Waste cooking oil also contains carbon that was originally part of the atmospheric CO_2 cycle, which can be recycled into asphalt to mitigate overall carbon emissions. Waste management benefits include the productive use of waste products, reducing landfill waste and soil and water pollution. Proper disposal of waste cooking oil can also help mitigate environmental hazards. The extended lifecycle of materials can be extended by reducing the frequency of road repairs and replacements, leading to less frequent resource extraction and lower environmental impact. Economic and environmental synergies can be achieved by utilizing waste cooking oil in asphalt mixtures, creating economic opportunities for waste management and recycling industries. However, quality control and lifecycle analysis are crucial to ensure the proper processing of waste cooking oil. Overall, using waste cooking oil in asphalt mixtures offers significant environmental benefits, contributing to a more sustainable approach to road construction and maintenance.

According to Pakistani regulations for asphalt recycling, just 15% of the aged asphalt material has been recycled on the Motorway (M-2) near Shekhupura at present [24]. Because of weak ties between academia and industry, there is a dearth of research, which contributes to the low percentage of recycled asphalt. Thus, the goal of the current study is to increase the amount of asphalt recycling in Pakistan by employing waste cooking oil (WCO) as rejuvenator. Rejuvenators are primarily used in recycled asphalt materials with the dual goals of lowering environmental pollution and recycling old asphalt for advantageous technical applications.

II. RESEARCH OBJECTIVES

1. To check the feasibility of recycled asphalt in Pakistan, using WCO as rejuvenator.
2. To compare the physical and rheological properties of recycled binder to neat binder using WCO as rejuvenator.
3. To evaluate the performance of asphalt mixture in conjunction with 50% recycled materials using WCO as rejuvenator.

III. MATERIALS AND METHODS

A. Aggregate

The virgin aggregate was extracted from Margalla, the province of Khyber Pakhtunkhwa and Punjab's largest aggregate source utilized in infrastructural projects. The aggregate was described in Table II with its physical characteristics according to BS and ASTM standards.

Table II: Physical Properties of Margalla Aggregate

Property	Unit	Standard	Value	Property	Unit	Standard	Value
Los Angeles abrasion value	%	ASTM C131 [25]	23.8	Soundness (Coarse aggregates)	%	ASTM C88 [29]	7.32
Flakiness index	%	BS 933-3 [26]	5.53	Soundness (Fine Aggregates)	%	ASTM C88 [29]	3.74
Water absorption	%	ASTM C127 [27]	0.845	Bulk density	kg/m^3	ASTM C29 [30]	1547
Specific gravity		ASTM C127 [27]	2.70	Impact Value	%	BS 812 [31]	14.4
Elongation index	%	ASTM D4791 [28]	4.2	Crushing value	%	BS 812 [31]	19.7

B. Asphalt Cement

The Attock refinery, Pakistan's major supplier of fresh and modified binder for road infrastructure, provided the 60/70 penetration grade asphalt binder. Based on the local temperature circumstances, the designated binder was chosen and is described in Table III. The physical and rheological characteristics of the aged asphalt binder, which was separated from RAP using a centrifuge method, are also characterized in Table III.

Table III: Physical Properties of Virgin and Recycled Binder

Property	Unit	Standard	Virgin Binder	RAP Binder
Penetration at 25ºC	$1/10^{th}$ of mm	ASTM D5 [32]	63.6	31
Softening point	ºC	ASTM D36 [33]	48.5	76
Ductility	cm	ASTM D113 [34]	102	37
Flash point	ºC	ASTM C142 [35]	265	278
Fire point	ºC	ASTM C142 [35]	283	299
Viscosity (135 ºC)	Pa.s	ASTM D4402 [36]	0.626	0.743
Viscosity (165 ºC)	Pa.s	ASTM D4402 [36]	0.171	0.664
G*/Sinδ at 64 ºC, 10 rad/sec	Kpa	ASTM D6373 [37]	1.32	8.73

IV. RESEARCH METHODOLOGY

Due to severe rutting and fatigue cracking, the Grand Trunk Road (G.T. Road) in Peshawar, which routes traffic to Afghanistan, was milled after its intended life was up. Recycled materials comprising aggregate coated with old bitumen, were acquired for the current investigation. In compliance with ASTM D2172, the aged binder was separated from the recycled mixture using a centrifuge method. Rejuvenating the recycled binder with 3%, 6%, 9%, 12%, and 15% waste cooking oil (WCO) allowed for the examination of its physical and rheological characteristics. The optimal rejuvenator content (ORC), that ought to be utilized in asphalt mixtures comprising recycled materials, was determined based on the aforementioned characterization. Following the process described in ASTM D1559, the virgin binder and aggregate were characterized. The Marshall Mix Design was then accomplished for the conventional mix, verifying the National Highway Authority (NHA) Class – A gradation as indicated in figure 1. This allowed for the determination of the optimum binder content (OBC).

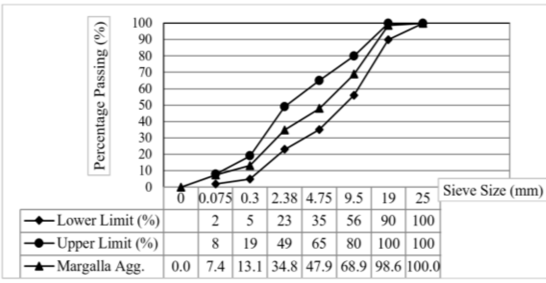

Fig. 1. Grain Size Distribution Curve

Total forty (40) number of asphalt specimens where twenty (20) number of specimens for conventional asphalt at 3%, 3.5%, 4%, 4.5%, and 5% bitumen content, and twenty (20) number of specimens for 50% recycled asphalt mixture, rejuvenated with 3%, 6%, 9%, 12%, and 15% WCO were prepared as per ASTM D1559. After being divided across metal pans, the RAP portions were heated at 160 °C for one hour. Following the RAP binder's mobilization, the rejuvenator was sprayed onto the recycled mixture and given 30 minutes to disperse throughout the recycled binder. At 160 degrees Celsius, separate mixes containing the binder and virgin aggregate were blended. Because of the rejuvenated RAP binder's temperature-viscosity connection, the virgin and rejuvenated recycled mixes were blended at a temperature of 160°C. The amount of virgin binder required for the mix design of recycled mixes was calculated using equation (1).

$$P_{nb} = \{(100^2 - rP_{sb})Pb/100(100-P_{sb})\}-\{(100-r)P_{sb}/(100-P_{sb})\} \text{------------------------} \quad (1)$$

(Asphalt Institute, 1986)

Where:

P_{nb} = The proportion of fresh asphalt binder in recycled mix, expressed as a whole number,

r = The percentage of new aggregate in the total amount of aggregate in the recycled mixture

P_b = Estimated recycled mix asphalt composition, calculated under the supposition that it is the same as 100% virgin HMA mixture.

P_{sb} = Percent binder content of recycled mixture.

In order to ascertain the most appropriate quantity of recyclable material to be employed in Pakistan, the performance of each asphalt mixture comprising the aforementioned recycled elements at the ORC and OBC was finally evaluated. Figure 2 presents the adopted approach in full.

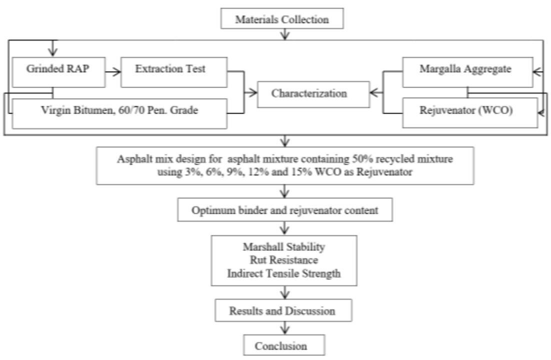

Fig. 2. Flow Chart showing Research Methodology for RAP Mixtures

C. Viscosity Test

The viscosity test of bitumen is a crucial method for determining the dynamic viscosity of bitumen at a specified temperature. It helps understand the flow characteristics of bitumen, which affect its performance in paving applications. The process involves heating the bitumen sample to a temperature slightly above the test temperature, filling it into the sample container, and maintaining the temperature throughout the test. The viscometer rotates the spindle at a predetermined speed, measuring the torque required to rotate the spindle. The viscosity reading is then recorded, and the test can be repeated at different temperatures to obtain a viscosity-temperature profile. The measured viscosity helps evaluate the workability and performance of bitumen at different temperatures. Lower viscosity indicates easier flow, while higher viscosity suggests stiffer bitumen. The rotational viscometer was used to measures the viscosity of virgin and recycled binder at 135°C, and 165°C, which helped in selecting asphalt mixing and compaction temperature using SuperPave viscosity – temperature relationship. The results were presented and discussed in section V in detail.

D. Wheel Tracking Test

A Wheel Tracker is a tool used to measure the rut depth caused by repeated wheel passes on a compacted asphalt sample. This equipment assesses the resistance of asphalt mixture against rutting under standard conditions of load and temperature. The asphalt sample is subjected to a loaded wheel, monitored under temperature ranging from 25°C to 55°C, as shown in Figure 3, and 4. The rut resistance is quantified as the rate of rutting during the test or the conclusive rut depth at the completion of the number of cycles. The wheel tracker is equipped with a temperature controlled cabinet and square slab specimens of asphalt mixtures are fitted to the tracker table. The performance of the asphalt mixture is determined in the laboratory using performance-based equipment that simulates actual field conditions. The asphalt specimens were prepared and subjected to 10,000 passes of a loaded wheel at temperature of 55 °C and the corresponding rut was monitored and discussed in section V in detail.

Fig. 3. Wheel Tracker [38]

Fig. 4. Wheel Tracker Solid Rubber Tyre [38]

E. Moisture Susceptibility Test

The moisture susceptibility test measures stripping resistance of a bituminous mix, evaluates the quality of mixtures in laboratory mix design, and measures moisture damage in asphalt pavements. It is conducted by loading a cylindrical specimen across its vertical diametric plane at a 50mm/min deformation rate and 25°C test temperature, recording the peak load at failure and calculating the Indirect Tensile Strength (ITS) of the specimen. After saturation, the samples are placed in the freezer for 14 hours while sealed in a plastic bag with 10 cc of water. The samples are frozen and then stored for two to three hours at room temperature (25 ºC) before spending a full day in a water bath at 60 ºC. The samples are then placed into the testing apparatus. The indirect tensile strength was determined using equation (2), and the tensile strength ratio (TSR) was obtained using equation (3).

$$S_t = 2000P/_{\pi t\ D} \quad (2)$$

Where, S_t = Tensile strength (KPa), t = thickness of the ample (mm), D = diameter of the sample (mm), and P = load (N).

$$TSR = S_{cond.}/S_{Uncond.} \quad (3)$$

Where, $S_{cond.}$ = Tensile strength of conditioned samples, and $S_{uncond.}$ = Tensile strength of unconditioned samples.

V. Results and Discussion

After extracting the 3.45% recycled asphalt binder through Centrifuge method, the consensus properties of the neat recycled binder, and rejuvenated recycled binder at each rejuvenator content of 3%, 6%, 9%, 12%, and 15% respectively, were determined, and presented in Table 5. It is well known that penetration refers the degree of hardness and softness of a particular asphalt binder. Therefore, while looking at the findings presented in Figure 5, it can be seen that when 3%, 6%, 9%, 12%, and 15% WCO was added to the recycled binder, the penetration values increased from 3.9 mm to 7.6 mm, respectively, as compared to that of unmodified recycled binder with penetration value of 3.9 mm. WCO of 9% is almost optimum to accelerate the value of recycled binder’s penetration to that of neat binder’s penetration of 6.33 mm. The mechanism behind this phenomenon of accelerating penetration’s value of binder to that of virgin’s binder is due to stimulation and mobility of the aged binder by the use of specified rejuvenator.

WCO of 12% is effective in declining the values of binder’s softening point from 76 ºC to 50 ºC which is almost parallel to that of neat binder’s softening point of 48.5 ºC. This declining in softening point is attributed to the thinning behavior of WCO when used as rejuvenator. Any percentage of the WCO as rejuvenator failed in raising the ductility of the aged binder to that of neat binder. Large percentages of the specified rejuvenator are required to improve ductility of the neat binder. However, large percentages of rejuvenator will adversely affect penetration and softening values of the aged binder. The flash and fire point showed a decreasing trend by incorporating rejuvenator, respectively. WCO of 6% proved to be nearly optimum in restoring the flash and fire point of aged recycled binder to that of neat binder.

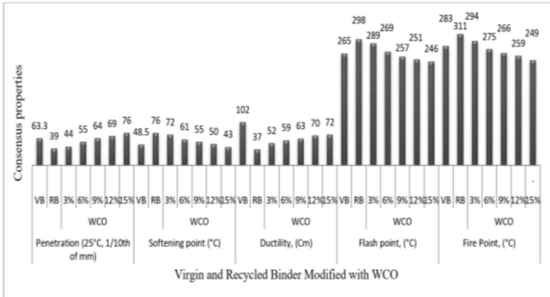

Fig. 5. Variation in Physical Properties of Virgin and Recycled Binder

The WCO is a promising additive for restoring the properties of aged bitumen, particularly in reducing its viscosity. WCO softens the bitumen, making it more workable and less prone to cracking. It also restores its flexibility, enhancing its resistance to thermal and fatigue cracking. The viscosity of the aged bitumen modified with WCO of 3%, 6%, 9%, 12%, and 15% has been shown in Figure 6, where the viscosity of the aged binder showed a decreasing trend with respect to that of the neat binder, respectively. This is attributed to the thinning behavior of the bitumen at specified temperature. The decline in stability at various percentages of WCO at 165 ºC is higher than at 135 ºC, as shown in Figure 6.

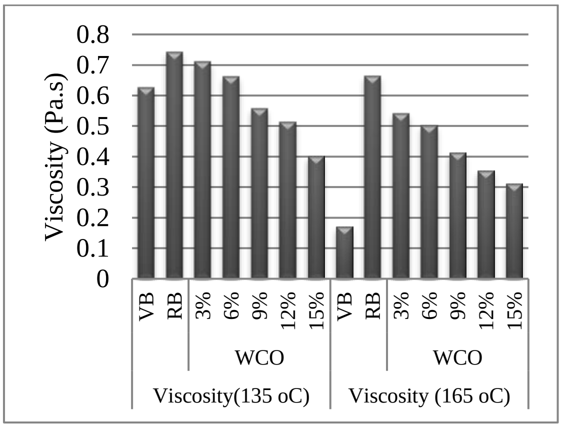

Fig. 6. Effect of WCO on Viscosity of Recycled Binder

Moreover, the results are generally consistent with the study where the consensus characteristics of aged bitumen of 30/40, 40/50, and 50/60 penetration grade were assessed using WCO as rejuvenator, ranging from 2% to 8% [39]. It was discovered that the WCO of 6% was ideal for bringing the required penetration of aged binders back to the virgin binder's 60/70 and 80/100 penetration grades. Similar results were found in another investigation where aged bitumen with a 40/50 penetration grade was restored to 80/100 penetration grade by adding 3% WCO to the bitumen [40]. The results of another investigation state that when the concentration of bio-oil (WCO) increases, the consensus features of recycled binder accelerate. For a 10% bio-oil dose, the penetration value was reported to be 100, while for a 20% bio-oil dosage, it was below 90. Conversely, a quick rise in the penetration value was seen in the bio-oil residue when the dosage of the oil was increased. The penetration values were 90, 120, and 160 (0.1 mm) for bio-oil concentrations of 3%, 10%, and 20%, respectively [41]. Another study examined the regeneration potential of WCO using aged bitumen of penetration grade 40/50 having a softening point of 50 °C. It has been shown that adding WCO lowers the softening point of the aged bitumen. The virgin 80/100 penetration grade bitumen's softening point value was similar to that of the aged bitumen at 3% WCO dosage.

The study prepared Marshall Specimens for the conventional asphalt with binder contents of 3.5%, 4%, 4.5%, 5%, and 5.5% by weight of Marshall briquette at 160 ^{o}C. The optimum binder content (OBC) was calculated using ASTM D1559 methodology, thereby plotting relationship between binder content, stability, density and air voids where the OBC was calculated against Maximum density, maximum stability, and 3 - 5% air voids. The conventional mix has an OBC of 4.42% at 160 ^{o}C, meeting the lowest stability criteria of 8.0 KN. The VMA, VFA, and AV met the requirements of 14 percent, 65 percent to 75 percent, and 3 to 5 percent standards, respectively. Table IV indicates that bulk specific gravity, density, and stability exhibit an inclining trend up to 4.5% binder content. This integrity is ascribed to the improved aggregate mobility towards voids in the asphalt mixture as a result of proper compaction and an optimal bitumen layer on the aggregate surface. But at 4.5% and 5% bitumen contents, the indicated qualities demonstrated a diminishing tendency because of the lubricating action of too much bitumen in the asphalt mixture.

Table IV: Mix Design Parameters of Conventional Asphalt Mixture

Symbol	**Unit**	**Mix Design Results**				
P_b	%	3.5	4	4.5	5	5.5
G_{mb}	-	2.326	2.340	2.383	2.310	2.312
G_{mm}	-	2.422	2.634	2.430	2.411	2.447
Density	Kg/m^3	2326	2340	2383	2310	2312
AV	%	5.57	4.31	4.39	4.76	3.81
VMA	%	14.45	13.64	13.14	13.42	13.77
VFA	%	57.33	65.56	70.63	79.54	80.47
S	KN	11.34	11.86	12.66	12.39	10.46
F	mm	5.42	4.49	3.65	3.87	5.33

The Marshall specimens comprising 50% recycled asphalt with 3.45% recycled binder, 4.42% OBC already determined for the conventional asphalt mix, and 50% conventional asphalt mix, were produced according to ASTM D1559 and rejuvenated with 3%, 6%, 9%, 12%, and 15% WCO and assessed for performance, and results were recorded in Table V. Results displayed in Table V showed that 9 % WCO give better performance in terms of Marshall Stability of 14.36 KN with corresponding flow of 3.11 mm in relation to conventional asphalt mixtures. The improvement in performance at 9% rejuvenator content is attributed to adequate interlocking in the asphalt mixture due to the stimulation and mobility of the recycled binder through the rejuvenator.

Table V: Mix Design Parameters of Marshall Specimen at Several Rejuvenator Contents

Virgin Binder (%)	**RAP Binder (%)**	**RAP Mix (%)**	**Virgin Mix (%)**	**Rejuvenator Type**	**Rejuvenator (%)**	**VMA (%)**	**VFA (%)**	**VTM (%)**	**Stability (KN)**	**Flow (mm)**
4.42	3.45	50	50	WCO	3	13.22	58.4	5.37	11.64	4.53
					6	14.79	56.63	4.58	12.74	4.04
					9	14.97	71.47	4.34	14.36	3.11
					12	14.62	72.55	4.87	13.10	3.54
					25	15.30	72.86	5.67	11.21	5.31

In order to determine rut depth or rutting resistance, a wheel tracking test was performed on a total of eighteen (18) samples that were created using the Marshal compactor. Three samples were used for each conventional and 50% recycled mixture at 3%, 6%, 9%, 12%, and 15% WCO, respectively. Every sample was put through a rigorous testing procedure that included 10,000 standard wheel turns at 55 °C and noting the depth of the rut after each revolution. In Figure 7, six distinct samples' average rut depth data versus 10,000 wheel tracking machine runs are shown, respectively. Every asphalt sample met the 12.5 mm maximum rut depth requirement. Figure 7 illustrates that after ten thousand passes, using 9% WCO, produced rut depths (6.65 mm), that was equivalent to that of a conventional asphalt mixture. This indicates that the 9% WCO concentration is optimal for recovering characteristics of the recycled asphalt that are comparable to that of a virgin asphalt mixture. However, due to the excessive lubricating impact and poor integrity of the asphalt mixture, 12% and 15% WCO concentration as rejuvenator in recycled asphalt mixture causes larger rut depth as compared to conventional asphalt. After ten thousand passes, the recycled mixture with 3% and 6% rejuvenator content had the least amount of rut depth, but because of its high stiffness, it may be susceptible to fatigue failure. As a result, the asphalt may not be able to tolerate cyclic loading at the specified rejuvenator content of 3% and 6%.

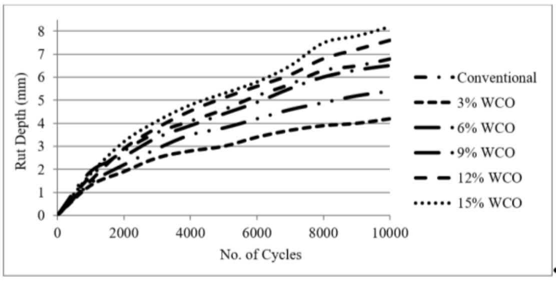

Fig. 7. Rut Depth with Respect to Number of Cycles

Following the determination of WCO's ideal rejuvenator content of 9%, a total of six (06) samples were generated using a Marshal compactor; three samples were made for each of the two groups such as 50% recycled asphalt at 9% rejuvenator content and conventional asphalt at 9%. Figure 8 shows how the conditioned and unconditioned modes' indirect tensile strength (ITS) varies with regard to mix type. According to the results of the moisture susceptibility test, test parameters including vacuum saturation and sample freezing and thawing speed up water damage. It's clear that adding 9% WCO as a rejuvenator to a 50% recycled asphalt mixture reduced the TSR values. The TSR values of recycled mixtures containing 50% WCO showed higher resistance to moisture damage as compared to those of conventional mixes, as shown in Figure 8. This is attributed to the effective mobilization of the recycled binder by the rejuvenator, adequate compaction of the recycled mixture, and excessive stiffness of the recycled binder in the recycled mixture.

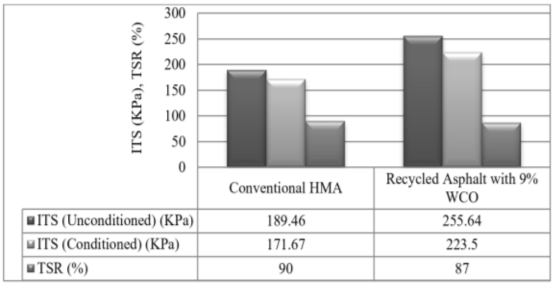

Fig. 8. Indirect Tensile Strength and Tensile Strength Ratio

Future studies have to concentrate on the applications of the different rejuvenator types (Table-I) in recycled asphalt binder and mixes. Rheological testing should be done on the binder, and fatigue resistance and the Hamburg Wheel Tracker test should be performed on the recycled mixture.

VI. CONCLUSION

The study led to the following conclusions:

The 50% recycled binder's penetration value, softening point, flash and fire point, and viscosity were found to be most effectively restored to virgin 60 – 70 penetration grade binder at 9% WCO, with no discernible increase in ductility. When compared to standard asphalt mixes, the asphalt mixture with 50% recycled materials at 9% WCO as rejuvenator performed better in terms of Marshall Stability. The asphalt mixture with 9% WCO content and 50% recycled materials demonstrated high rut resistance with minimum rut depth comparable to conventional asphalt mixture because of the asphalt mixture's adequate interlocking caused by the recycled binder's stimulation and mobility through the rejuvenator. The stiffness of the recycled mixture was nearly equal to that of the traditional asphalt mixture, according to the flow values of an asphalt mixture with 50% recycled materials at 9% WCO content as rejuvenator. Because of the rejuvenator's efficient mobilization of the recycled binder, and the recycled mixture's appropriate compaction, the TSR values of the recycled mixture containing 9% WCO demonstrated results that were equivalent to those of the conventional mix.

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