Utilizing Waste Engine Oil and Soft Binder as Additives to Mitigate the Moisture Damage of Asphalt Mixtures

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ABSTRACT

The deterioration of asphalt pavements caused by moisture is a significant concern for asphalt pavement construction companies. To improve this characteristic, this research aims to determine how rejuvenators and flexible compounds, affect the resistance of asphalt concrete to moisture. This study investigates the effects of incorporating Waste Engine Oil (WEO), an easily obtainable and economical substance, into a maturing mixture. The action of this substance resulted in strengthening the physical and chemical characteristics of the bitumen, as well as mitigating the adverse effects caused by moisture. The various degrees of bitumen penetration ranged from 40-50 to 80-1. Extremely small limestone dust particles measuring 19.0 mm, were utilized as mineral infill in the aggregate grade. To enhance the Marshall characteristics, treatments containing 0%, 2%, 4%, and 6% WEO by weight of binder were implemented after filtration. The most advanced Marshall had a WEO content of 6% and an asphalt grade ranging from 85-100, while stability and resistance to moisture degradation were observed. Compared to combinations lacking WEO, the compressive strength and the indirect tensile strength value, were determined to find the Index of Retained Strength (IRS) and Tensile Strength Ratio (TSR). This reduced moisture susceptibility as TSR% and IRS% values increased by approximately 1.22% and 0.9%, respectively.

Keywords-rejuvenator (WEO); unaged mixture; soft binder; indirect tensile strength; moisture damage

I. INTRODUCTION

Moisture-induced damage in asphaltic pavement might be considered a severe defect that contributes to the growth of other distresses, such as permanent deformation and fatigue cracking [1]. Asphalt pavement layers' principal source of distress is the moisture deterioration in asphalt concrete pavements. The repeated contact of asphalt surfaces with water is one of the most important elements influencing the reliability of Hot Mix Asphalt (HMA). Water-induced deterioration in HMA layers might be initiated by two different causes: a lack of adhesion and cohesiveness. In the initial mechanism, water becomes caught between the bitumen coating and the aggregate, pulling the asphalt film away and exposing the aggregate to the elements. This is because aggregates have a higher thirst for moisture than the bitumen binder. The other mechanism involves water interacting with the asphalt cement, which weakens cohesiveness within the bitumen cement. The asphalt mixture strength significantly decreases [2, 3]. In general, moisture sensitivity, contributes to the decrease of the asphalt mixture durability. The poor endurance of the asphalt mixture is caused by the wear of the cohesive bond, mainly by penetration. The cohesive bond is formed by the binder and then the aggregate. The process of moisture penetration usually starts from the top surface and goes down. Susceptibility to moisture may be considered in the laboratory by evaluating unconditioned and moisture-conditioned materials for stability, such as the resilience modulus and tensile strength [4-6]

Cracking, fatigue and raveling are some of the problems caused by moisture, for this reason the use of asphalt is considered a disadvantage. [7-9] According to previous tests, a softer virgin binder did not improve the mixtures' resistance to fracture propagation. In addition, using higher proportions of the virgin binder is not cost-effective. In asphalt pavements, oxidative aging is a factor that contributes to the brittleness of the pavement as well as to severe pavement cracking. When asphalt is exposed to oxygen in the air, its composition changes over time. Asphalt becomes stiff and rigid due to an oxygen reaction [10]. The rising viscosity and resulting toughness during aging affect the performance requirements of bitumen binder and mixes. Authors in [11, 12] studied the possibility of reusing leftover cooking oil as a rejuvenator in recycled combinations. They claimed that utilizing used cooking oil restored the characteristics of bitumen. Moisture degradation is a significant issue affecting the longevity of asphalt mixes. To meet performance requirements, the asphalt pavement must exhibit characteristics such as the capacity to handle traffic loads under specific climatic circumstances and withstand any damage over its whole service life. As mentioned above, water damage reduces a material's lifespan, because water introduces a destructive element into the mix by attacking individual particles or the entire structure [13-15]. Moisture reparation in asphalt combinations is generally defined as an advanced proper corrosion of a pavement combination, caused by loss of cohesion resistance (strength) with the asphalt binder and a breaking of the adhesive bond between the asphalt binder and the aggregate in the mix (stripping) [16].

Numerous measurements have been recorded in HMA to mitigate moisture-induced deterioration in asphalt pavements. To enhance the durability of HMA against moisture degradation, revitalizing agents in the form of liquid agents were employed [17]. Regarding the WEO addition, moisture infiltrates the interface between the aggregate and binder, causing the asphalt binder to be displaced from the aggregate surface. In extreme circumstances, this results in the rupture of the adhesive bond amid the binder and aggregate. According to [18], mixing residual oil with the reference mixture exhibits superior performance. Except for revitalized mixtures, which become more susceptible to moisture with age, the results of the moisture susceptibility tests indicated that aging has no significant effect on the moisture resistance of the mixtures. Regarding WEO, numerous studies reveal that is also one of the discussed oil-based rejuvenators [19]. The performance parameters of asphalt mixtures containing 100% recycled asphalt and RAP bitumen with six distinct rejuvenators were evaluated. WEO was employed to enhance RAP bitumen during the investigation. The authors asserted that the rejuvenated RAP bitumen passed the rutting criterion and achieved a performance grade equivalent to that of the virgin bitumen. Investigating the moisture sensitivity of the hot mix bitumen is the principal objective of this research. An increasing number of studies [20-22] are examining the environmental and economic viability of utilizing oils, such as "bio-oil," "waste cooking oil," and WEO to modify or promote conventional asphalt. The vehicle maintenance and repair process has contributed significantly to the WEO produced due to the exponential growth in the vehicle population. Unconcerned littering has occurred in numerous WEOs, endangering the health of humans, the environment, and contaminating the soil and water [23], rendering research in WEO recycling essential. Research into the potential benefits of mixing WEO with asphalt is ongoing [24, 25]; preliminary findings suggest that WEO may be helpful as an asphalt modifier, since it unquestionably rises in economic worth when utilized in such a way [26]. According to a research conducted by the ASTM, Re-refined Apparatus Oil Bottoms (REOBs) added to bitumen mixtures improved their efficacy. Another study indicated that exceeding 15% of WEO addition in asphalt-WEO mixtures negatively impacts low-temperature performance. Asphalt pavement modified with WEO develops early fracture when the concentration of WEO exceeds 15%. According to [27], the primary factors contributing to road failures in Ontario were physical fortification and insufficient strain tolerance. Even though most studies have shown that WEO can be utilized to modify bitumen, divergent opinions remain. This research aims to examine rejuvenation's impact on asphalt mixtures composed of WEO, a flexible binder (grade 85–100 asphalt), and AC (40/50). WEO was incorporated into the mixtures at specific concentrations of 2%, 4%, and 6%. The principal objective of the hot mix asphalt investigation is to ascertain the moisture sensitivity of this technique. By incorporating WEO and asphalt grade (85-100), this research aims to improve the resistance of asphalt mixtures, extend their service life, and strengthen their resistance to moisture reparation. These objectives will be achieved through the measurement of tensile and compressive strengths, as well as the calculation of the index of reserved strength ratio.

II. EXPERIMENTAL WORK AND MATERIALS

A. Materials

1) Asphalt

This study used Al-Daurah Refinery's Asphalt Cement (AC) with penetration grades of 40-50 and 85–100. The physical features of the asphalt cement were investigated to meet the State Corporation for Roads and Bridges (SCRB) standards. The physical features of asphalt cement are given in Table I.

TABLE I. ASPHALT CEMENT'S PHYSICAL CHARACTERISTICS

Test	Units	Penetration Grade (40-50)		Penetration Grade (85-100)		ASTM Designation
		Result	SCRB Specification limits	Result	SCRB Specification limits	
Penetration (25°C, 100g, 5 s)	1/10 mm	44	40-50	92	85-100	D-5
Softening point (Ring & Ball)	°C	51	---	33	---	D-36
Ductility (25 °C, 5 cm/min)	cm	95	>100	129	>100	D-113
Specific gravity (25 °C)	---	1.042	---	1.03	---	D-70
Flash Point (Cleveland Open up)	°C	309	>232	242	>232	D-92

2) *Coarse Aggregates*

Al-Nibaee Quarry supplied the coarse crushed aggregate. It falls between the sieve sizes of 19 mm and 4.75 mm. Table II presents the findings based on the indicated limit [28].

TABLE II. COARSE AGGREGATE PHYSICAL PROPERTIES

Property	ASTM Specification	Result	SCRB Specification
Bulk Specific Gravity	C-127	2.57	----
Apparent Specific Gravity	C-127	2.604	----
Percent Water Absorption	C-127	0.58	----
Percent Wear	C-131	15.27	30 Max

3) *Fine Aggregate*

A similar coarse aggregate supplier supplied the fine crushed aggregate with a display size from 4.75 mm to 0.075 mm. Table III illustrates the fine aggregate's physical properties. The results demonstrate that the physical properties satisfy SCRB's (2003) requirements.

TABLE III. PHYSICAL PROPERTIES OF FINE AGGREGATE

Property	Result
% Passing N0.200	95
Specific gravity	2.68

4) *Mineral Filler*

Limestone dust was used as the mineral filler for the asphalt concrete mixture. The limestone dust passing through a 0.075 mm sieve was added to the mixtures as the filler. The filler was found at an Iraqi lime mill in Karbala. The physical characteristics of filler are provided in Table IV.

5) *Waste Engine Oil (WEO)*

The WEO is any petrochemical or synthetic oil whose impurities have rendered it devoid of its initial characteristics or unfit for its intended use. The WEO, which was extracted from used car oil, was used as a revitalizing agent. When selecting a rejuvenating agent for the bitumen mixture, its compatibility with the aged binder is critical. Considering this, the asphalt binder was diluted with four distinct proportions of residual engine oil (0%, 2%, 4%, and 6%) in this investigation. The physical appearances of the WEO utilized in this investigation are detailed in Table V. The residual engine oil underwent multiple filtration processes utilizing filter paper to remove impurities. It was then heated to the point of evaporation to remove water molecules. In this experiment, the asphalt and regenerator were combined at 150 °C for 5 min to attain a homogeneous regenerative mixture. The visual representation of the filtered WEO is depicted in Figure 1.

TABLE IV. PHYSICAL PROPERTIES OF MINERAL FILLER (LIMESTONE DUST)

Prop.	ASTM Specification	Result	SCRB Specification
Bulk Sp. Gr.	C-128	2.64	---
Appa. Sp. Gr.	C-128	2.622	---
%Water Abs.	C-128	0.732	---

TABLE V. PHYSICAL PROPERTIES OF WASTE ENGINE OIL

Test result	Units	Result	Test result	Units
Penetration (25°C, 100 g, 5 s)	1/100 mm	38	Penetration (25°C, 100 g, 5 s)	1/100 mm
Softening Point (Ring & Ball)	°C	53	Softening Point (Ring & Ball)	°C
Specific Gravity (g/cm³)	----	0.865	Specific Gravity (g/cm³)	----
Kinematics Viscosity at 135 °C (CST)	cSt	3.84	Kinematics Viscosity at 135 °C (CST)	cSt

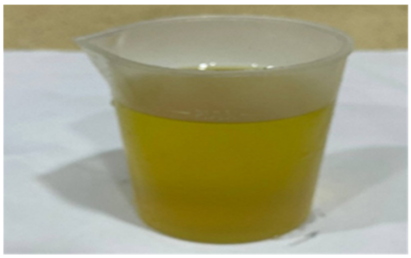

Fig. 1. WEO after filtering.

B. *The Gradation of Aggregate Design*

The crushed stone and filler grades were chosen to meet SCRB specifications, with a negligible determined size of 12.5 mm and a wearing option type IIIA. Figure 2 and Table VI show the specific aggregate gradation used in this study.

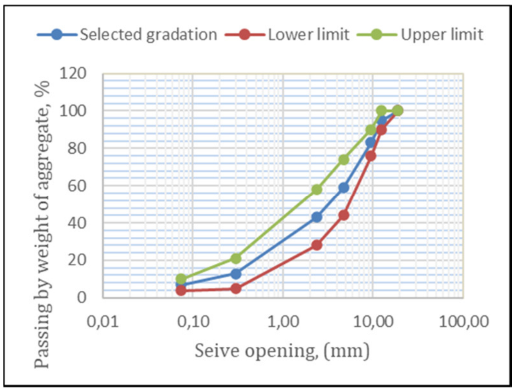

Fig. 2. Aggregate gradation design.

TABLE VI. AGGREGATE GRADATION FOR THE SURFACE LAYER (TYPE IIIA)

Sieve size	Sieve opening (mm)	Specification passing range (%)	Selected gradation
3/4"	19	100	100
1/2"	12.5	90-100	95
3/8"	9.5	76-90	83
No.4	4.75	44-76	59
No.8	2.36	28-58	43
No.50	0.3	5-21	13
No.200	0.075	4-10	7

1) Asphalt Mixture Tests

a) Marshall Test

Marshall tests investigating stability, density, and air voids were conducted on all mixtures arranged in this study based on ASTM D2726-08 specifications. Three samples of each mix were tested using the aggregate. The Optimum Asphalt Content (mean of the maximum stability, maximum bulk density, and 4% Air Voids) was utilized to approve the wearing course layer % for an Ordinary Portland Cement (OPC) content of 4.9%. The asphalt criteria were created by performing the Marshall test on the asphalt specimens that were 63.5 mm tall and 101.6 mm in diameter. The specimens were prepared using an asphalt compactor with 75 blows per side: the optimal asphalt concentration, bulk specific gravity, air voids, voids in mineral aggregates, Marshall stability, and flow value were among these characteristics explored in the Roads Materials Lab in the Civil Engineering Department. This test was performed on specimens submerged in a water bath (at a heat of 30 °C - 40 °C) for 60 min and then loaded to failure at a rate of 50.8 mm/min. Figure 3 depicts the Marshall test process.

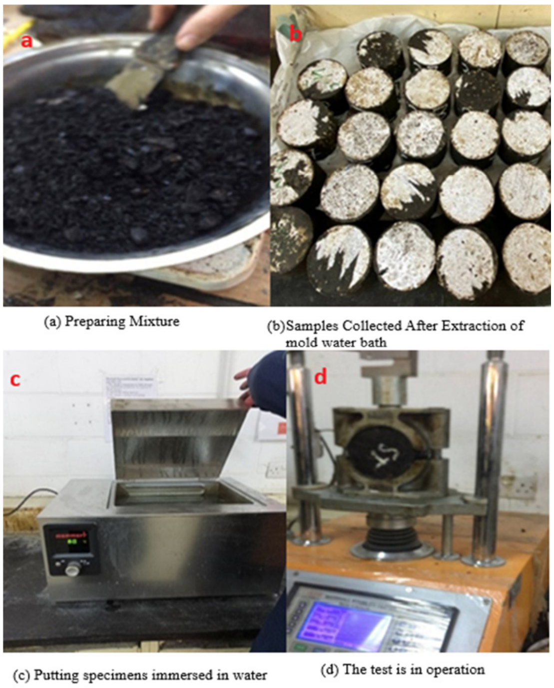

Fig. 3. Testing of Marshall specimens.

b) Tensile Strength Ratio (TSR) Test

The testing process involves creating and evaluating asphalt concrete samples to see how moisture impacts the tensile strength of the asphalt mix. The test was conducted according to ASTM D-4867. The samples used in this test were subjected to the appropriate blows (45, 55, 65, 75) to produce 7±1% air voids, as calculated by the job-mix formulation. As illustrated in Figure 4, to attain this percentage, 48 blows were used. Marshall samples were collected into four sets of two collections, each with six samples, after calculating the number of blows. The primary group of unconditioned samples was immersed in water for 30 min at 25 °C. After that, the Indirect tensile Strength (ITS) values found in each sample were averaged. The second bunch was vacuum sealed at 25 °C and submerged in filtered water to eliminate air. The samples were then kept frozen at -18±3 °C for 16 hours. After the freezing phase (conditioned specimens), the models were thawed in water immersion at 60.0 °C for 24 hours to complete the procedure. These samples were obtained and kept in 25.0 °C water immersion for an hour before the ITS could be measured. For the ITS computations, the ASTM D-6931-12 approach is used. The loading scheme held the sample, and it was ensured that the loading strips were perpendicular to the diametrical level and center of the sample. The length of the uploading strips topped the width of the specimen. The sample was exposed to a diametrical loading of 50.8 mm/min until failure. This test's technique is displayed in Figure 5.

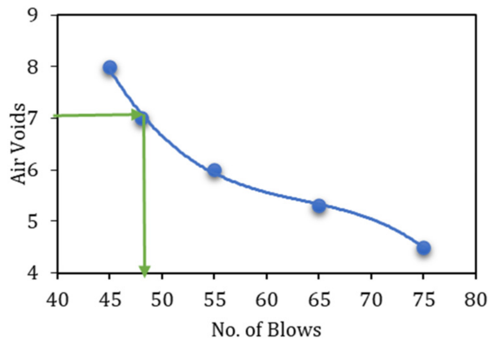

Fig. 4. Relationship between the number of blows and the proportion of air voids.

Fig. 5. Testing of TSR specimens.

The ITS value was obtained by:

$$ITS = \frac{2000\ Pult}{\pi\ t\ D} \qquad (1)$$

where ITS is the Indirect Tensile Strength (kPa), Pult is the ultimate applied load required for the specimen to fail (N), t is the thickness of the sample (mm), and D is the diameter of the sample (mm).

After the calculation of ITS for each set of conditioned and unconditioned specimens, the tensile strength ratio was calculated as:

$$TSR\ \% = \frac{con.ITS}{un\ con.ITS} \times 100 \quad (2)$$

where TSR = Tensile Strength Ratio (%), con.ITS = average ITS of the moisture–conditioned samples (kPa), un con.ITS = average ITS unconditioned (dry) samples (kPa).

The minimum TSR value is 80% according to the ASTM D-4867-09.

c) Compressive Strength Test

This test procedure evaluated the asphalt mixtures that meet the moisture susceptibility requirements as stated in ASTM D-1074 (2015). Four cylinder-shaped specimens measuring 101.6 mm × 101.6 mm were created by condensing the mixture (ASTM D-1074). The samples were separated into four sections of two sets for several samples (48 samples), with each containing six samples. The sample was divided into two parts, and three samples were evaluated for compressive resistance after being immersed in water at 25 °C for 4 hours. For each percentage of WEO, three specimens were initialized and then placed in the air route for 24 hours at 25 °C. The compression test was performed, and the average assessment of the three samples was "Dry specimens". The other group was put through a compressive strength test after being stored in a water immersion at 60 C° for 24 hours, then taken out and cooled at 25 °C for 2 hours. The average value for this group was the index of retained strength. The maximum resistance load before failure was ascertained by consistently administering a compressive load at a ratio of 0.2 inches/min (5.08 mm/min). The IRS value should be at least 70%:

$$IRS = (S2/S1) \times 100 \quad (3)$$

where IRS is the index of recollected strength (%), S2 is the average compressive strength of wet specimens (kPa), and S1 is the average compressive strength of dry specimens (kPa).

III. RESULT AND OBSERVATION

A. Marshall Test

Figure 6 shows that all mixes satisfy the minimal stability criterion (8 kN) for roads with heavy traffic. The stability of the mixture gradually increases by approximately (29.13%, 0.75%, and 1.92%) when waste oil is added in concentrations of (2%, 4%, and 6%). It was noted that the stability increased when used oil was added in relation to the stability of the soft binder. The increase in the mixture stability emerges from increasing the bonding between the materials of which the asphalt concrete consists. Figure 7 illustrates the link between the WEO content, asphalt grade (85-100), and the Marshall flow. Flow values were observed to decrease as WEO concentration increased. This means that the mixture was less rigid when the amount of WEO was raised. This could be attributed to the good connection provided by the asphalt binders and the collective particles in mixtures. However, flow values between the required specifications (2 mm and 4 mm) were measured. The density improved as the WEO concentration increased, as seen in Figure 8. The largest increase in bulk density was when waste engine oil at a rate of 6% was added. This means that due to the rise in the viscosity of the asphalt and when the WEO content of the combination is enlarged, the density of the mix increases when compacted at the same pressure.

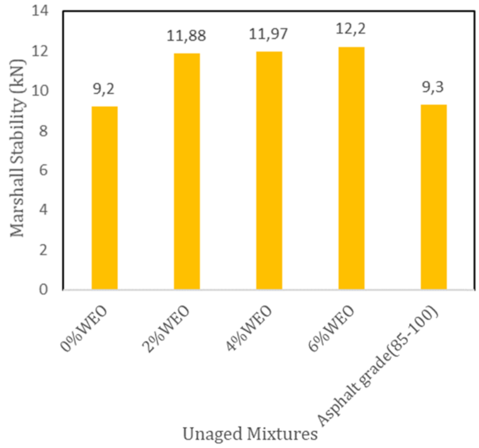

Fig. 6. Effect of WEO and asphalt grade (85-100) on Marshall stability.

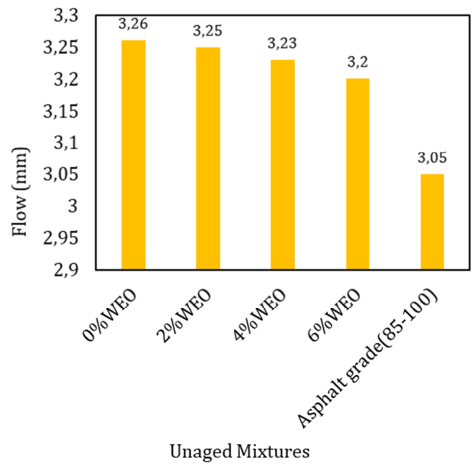

Fig. 7. Effect of WEO and asphalt grade (85-100) on Marshall flow.

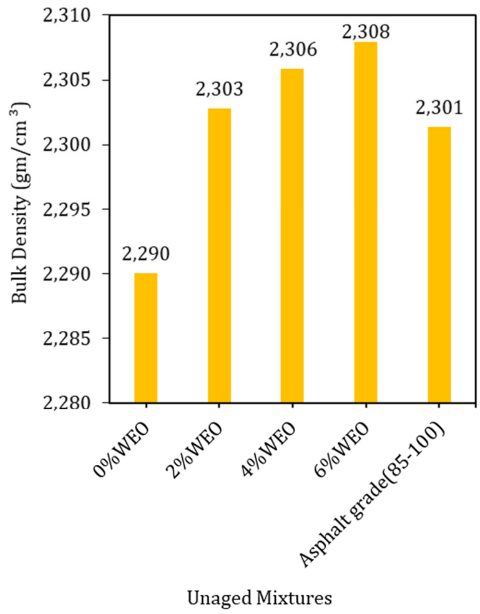

Fig. 8. Effect of WEO and asphalt grade (85-100) on bulk density.

As observed in Figure 9, raising the waste engine oil content caused better air void values. All mixtures, including rejuvenated and soft binder, could comply with the volumetric standards regarding the air voids to accomplish the preferred air void content in the mixtures. Figure 10 demonstrates that the number of voids filled with bitumen is increased along with the proportion of WEO in the mixes, while it is decreased with the increase of the renewed material and the soft binder. As evidenced in Figure 11, the amount of void space in the mineral aggregates, which comprise voids of air and voids containing effective bitumen, is determined as a proportion of the total volume and the distance between the aggregates in the compacted asphalt mix increases equivalently to the WEO content increase. This decrease in VMA is due to a rise in the bulk density [29, 30].

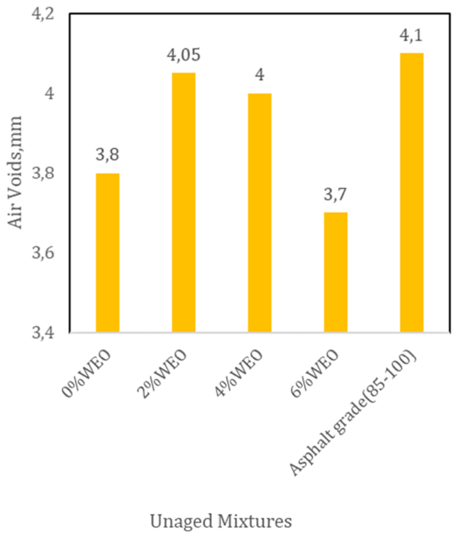

Fig. 9. Effect of WEO and asphalt grade (85-100) on air voids.

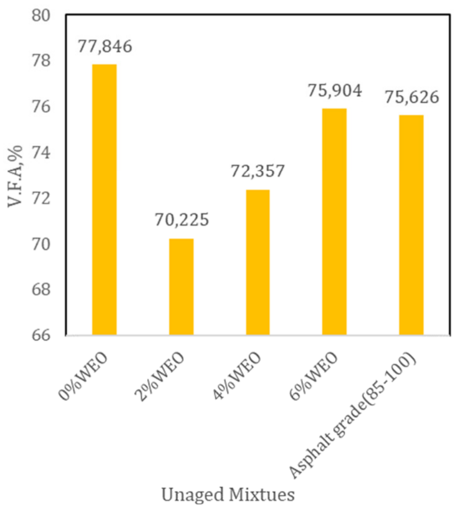

Fig. 10. Effect of WEO and asphalt grade (85-100) on VFA.

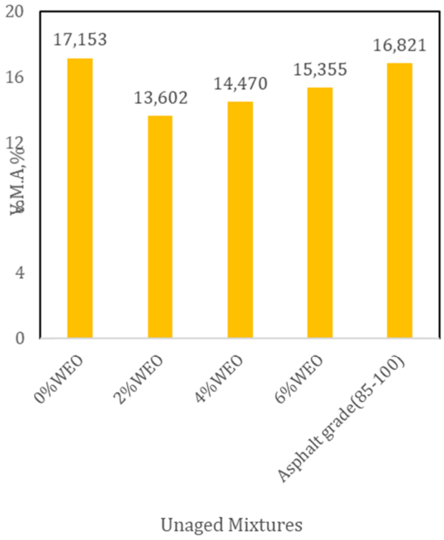

Fig. 11. Effect of WEO and asphalt grade (85-100) on VMA.

B. Tensile Strength Ratio (TSR) Test

An advanced ITS significance suggests greater resilience to low-temperature cracking and fatigue fracture in an asphalt pavement [32]. When a rejuvenating waste oil of asphalt grade (85–100) is used, as seen in Figure 12, the ITS, when a rejuvenating waste oil and soft asphalt grade (85–100) in the case of the control mix, appears to increase by about 0.34%, 3.47%, and 0.72% at unconditioned mixtures and also increases by about 0.99%, 5.65%, and 1.94% at conditioned mixtures [17, 32].

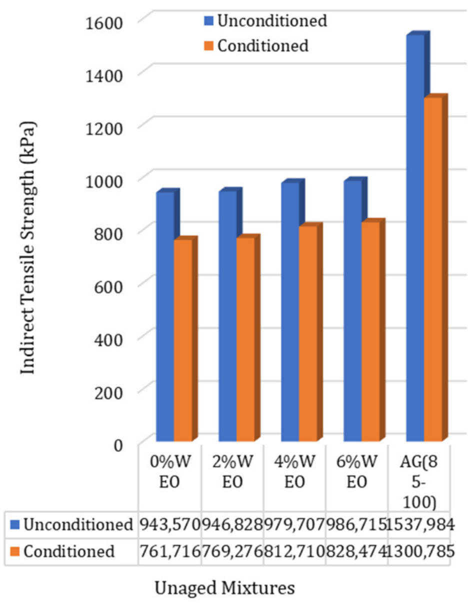

Fig. 12. Effect of WEO and asphalt grade (85-100) on unconditioned and conditioned ITS.

Compared to the control mix and various WEO-added percentages, the best value is noted at asphalt grade (85–100). This implies that WEO is less sensitive to moisture than the other outcomes. When the percentages of WEO are 0%, it is more vulnerable to moisture damage, as displayed in Figure 13. A minimum of 79% of the ultimate burden is considered permissible. The displacement of the reinforced girders experienced a marginal reduction of 9%–18% for B1S and B2S throughout this period, while the former was reduced by nearly the same amount (11%–19%) for B1SW and B2SW. In each case, the member with the end anchorage has a smaller drop in the load value, higher strength, and much more stiffness [10]. The CFRP girder strengthened with CFRP laminate and end U-wrapping of CFRP sheet demonstrates an increase in deflection at the maximum load, while the ability of the members with an anchor to preserve their ductile response is also displayed. The ultimate displacement increased significantly for specimens strengthened with laminates only and laminates with end anchorage. The increase reached 18.16% and 11.39%.

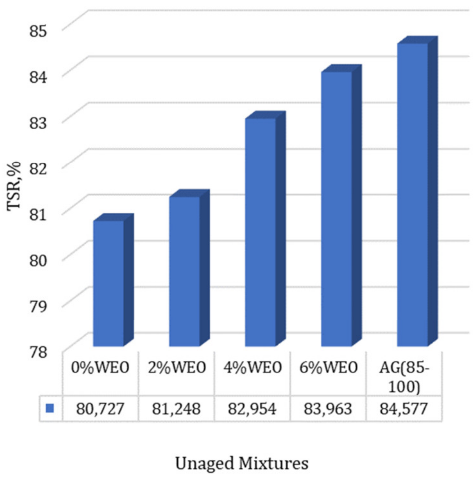

Fig. 13. Effect of WEO and asphalt grade (85-100) on TRS.

C. Compressive Strength Test

As demonstrated in Figure 14, the compressive strength of the mixture improved as the percentage of WEO component and soft binder asphalt grade (85–100) increased. However, the compressive strength ratings for dry specimens are higher than those for wet specimens. However, these values increased as the WEO content increased, such as at (2%, 4%, and 6%), the WEO content for dry compressive strength increased around (2.29%, 1.34%, and 1.207%), and the resistance to water damage increased around (2.88%, 2.415%, and 2.122%) for wet specimens. The allowed assessment of the directory of the maintained strength for the surface layer, according to SCRB R/9, 2003 requirements, is at least 70%. The IRS consequences presented that the combination performed well, and the IRS rose as the WEO level in the HMA increased. However, all control combinations met the surface layer specification criteria of SCRB R/9, 2003. In Figure 15, it is exhibited that the IRS (resistance to moisture damage) increases when the proportion of WEO increases (0.57%, 1.05%, 0.9%), with the addition of waste oil (2%, 4%, 6%) [33-36].

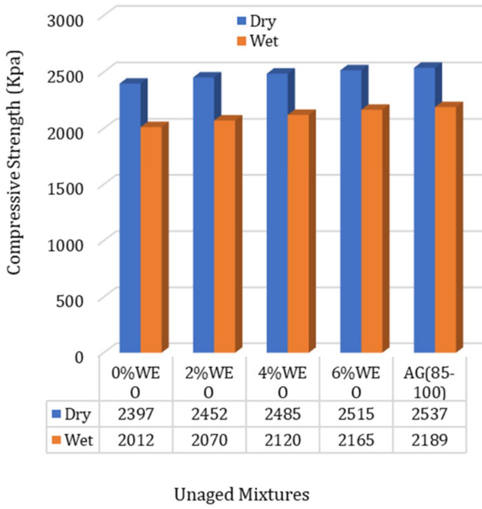

Fig. 14. Effect of WEO and asphalt grade (85-100) on compressive strength.

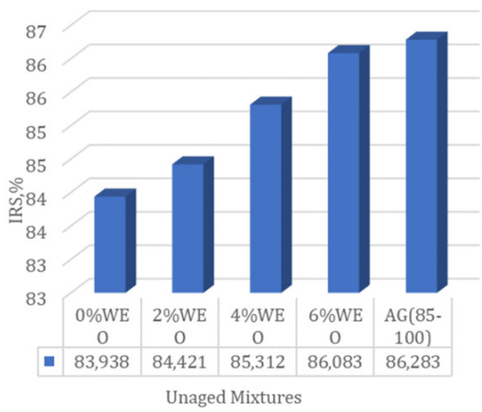

Fig. 15. Effect of WEO and asphalt grade (85-100) on IRS.

IV. CONCLUSIONS

1. WEO and soft binder were used to enhance the properties of the asphalt after exposure to external conditions, and reduce moisture damage. It was noted that when the proportions of the used ingredients increased, the prices of ITS and TSR increased. In contrast, the increase in IRS clearly shows the effects of active asphalt mixture elements and the increase of its resistance on moisture. It was detected that there was a rise in the stability of the mix when increasing the regenerator and a decrease in the flow.

2. This is due to a reduction in air voids and an enlargement in bulk density due to the penetration of the renewed asphalt between the aggregate particles covering them completely. This helps in the pavement's resistance to moisture damage preventing slippage and breakage due to increased traffic loads and its exposure to external factors except the oxidation and others [29].

3. When (2%, 4%, and 6%) WEO were utilized, the TSR value increased by (0.65%, 2.09%, and 1.22%) in the assessment of the controller asphalt combination.
4. At 6% WEO addition, stability increased, reaching a maximum of 1.92%.
5. When testing the compressive strength, using (2%, 4%, and 6%) of waste engine oil, the dry compressive strength increased by 2.29%, 1.34%, and 1.2% compared to a standard asphalt mixture. The wet compressive strength improved by 2.88%, 2.415%, and 2.12% when using the same percentage of WEO, increasing its moisture resistance.
6. The IRS values at 6% WEO addition are significantly higher than those at 0% and 2%, with the asphalt grade (85-100) exhibiting the best value.

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