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Enhancing Bitumen Rheological Properties with Recycled Waste Lubricating Oil

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ABSTRACT

Asphalt mixtures, widely used in road paving due to their resistance to corrosion under various conditions and flexibility, allow for property modifications to improve the road's quality and extend its service life. Utilizing waste reduces environmental risks, contributes to sustainable development, and enhances the properties of bitumen and asphalt mixtures. Recycling allows us to dispose of these materials in various forms. This study investigates the possibility of recycling lubricating oil waste to improve the quality of asphalt and convert it into asphalt suitable for use. The study used four percentages of lubricating oil waste by weight of Shirqat bitumen, with a penetration grade of 20–30. The four percentages used to lubricate oil waste are (0, 3, 6, 9)% by weight of bitumen. The results demonstrated that adding used lubricants can improve the properties of bitumen with a penetration grade of 20–30, making it suitable for use in Iraq's southern and central regions, which typically use bitumen with a penetration grade of 40–50. Studies also showed an increase in asphalt's susceptibility temperature, indicating the possibility of using it in the cold region. However, the results were not satisfactory for high temperatures. This study is considered good from an economic and environmental perspective in terms of recycling waste and using it to improve the performance of asphalt in cold areas, including Iraq's northern regions. The best percentage of lubricating oils is 6 per cent as an additive to asphalt, which gives it specifications suitable for the climate of most regions of Iraq, and the results are consistent with Iraqi materials and construction standards.

1. INTRODUCTION

Bitumen was one of the earliest construction materials used on Earth. Around 6,000 B.C., the ancient Sumerians utilized bitumen to seal their transportation vessels. Subsequently, many ancient civilizations employed naturally occurring pavements for various applications, such as preservation in Egypt, the Indus Valley's open-air showers, and waterproofing. By the mid-1800s, both France and America commonly used bituminous rock for pavement construction. In 1876, the first asphalt road was constructed in Washington. The discovery of oil at the turn of the 20th century led to the development of refined asphalt, which remains in use today [1, 2].

The rheological and mechanical qualities of bitumen have found numerous applications in road pavement [3, 4]. Asphalt properties, such as adhesion and deformation between mixture components, affect pavement performance [5].

Conventional bitumen has several deteriorations caused by heavy loads and unfavorable weather, including extreme temperatures and water seeping through the asphalt's base. Although there are numerous advantages to selecting a primary ore for bitumen production, only a small number of ores can provide bitumen that is acceptable for paving roads [3, 5]. For this reason, enhancing the asphalt's characteristics is crucial to enhancing the performance of road paving. Industrial additives such as fibers, polymers, extenders, fillers, antioxidants, and waste materials can enhance the properties of asphalt [6, 7]. Commercial additives have the potential to enhance mixing performance, but their high cost necessitates the need for good but less expensive alternatives [8]. The use of additives in asphalt mixes has recently grown in popularity as a way to improve the characteristics and functionality of this popular building material. Additives improve the strength, flexibility, crack resistance, and durability of asphalt mixes. Engineers and building experts may combine these compounds with asphalt to create pavements that can withstand high traffic volumes, harsh weather, and the test of time. This essay will examine how additives may improve the characteristics of asphalt, with particular attention to how they might increase strength and durability, increase flexibility and fracture resistance, and improve performance in adverse weather [9-12]. However, the massive amounts of waste generated from the consumption and disposal of materials such as used cooking oil, plastics like high-density polyethylene, and motor oil pose a problem for environmental sustainability. Instead, this study's application of waste fuel oil as modified bitumen illustrates the need for alternative low-cost adjustments. American fast food and restaurant chains donate almost 3 billion gallons of used cooking oil annually [13, 14]. The USA and Europe collect between 1.7 and 3.5 million metric tonnes of waste lubricant annually, also known as lubricating lubricants. This massive volume of wasted lubricating oil has had a significant impact on both environmental and economic concerns. Manufacturing these gadgets can cost millions of dollars, and their disposal contributes to pollution. Incorporating these gadgets into soil, water, or even small-grade coal can release dangerous metals and other toxins into the environment. Another way to remediate trash is to blend it with asphalt. This accomplishes the twin goals of improving the properties of the bitumen and asphalt mixture, as well as getting rid of trash [15]. This study examines how adding waste lubricating oil can alter the characteristics of bitumen for use in road surface applications. To achieve the study's objectives, we created waste lubricating oil (WLO)-modified bitumen by adding different amounts of binder weight to basic bitumen and testing its various properties, such as its specific gravity penetration and softening point. We conducted additional experiments with the altered asphalt binder.

2. MATERIALS AND METHODS

2.1 Asphalt

The Alsherqat refinery factory provided the bitumen with a penetration grade (20-30), which served as the base bitumen for this study. The physical and rheological tests for the asphalt used in this study are presented in Table 1.

Table 1. The bitumen's physical properties in usage

Properties	ASTM Specification	The Unit and Test Conditions	Pure Bitumen
Penetration	"ASTM D.5"	100 gm, 77°F	22
Softening Point	"ASTM.36"	Ring and Ball inspect	61
Specific gravity	"ASTM D.70"	77°F	1.06
ductility	"ASTM D.113"	Cm, 77°F	97
Flash point	"ASTM D-92"	°C, Cleveland	290°C
Fire point			340°C
Viscosity		Cp, 135°C Cp, 160°C	184.5Cp 539.5

(1.8°C= °F-32)
°C = Celsius degree, F = Fahrenheit degrees.

2.2 Wasted lubricant oil

A variety of sources, including two plants in the Anbar City region, provide waste lubricant oil (WLO) for recovery after it has traveled hundreds of kilometers in an engine. We clean the filters before use to remove any impurities. The tests for the waste lubricated oil used in this study are presented in Table 2.

Table 2. The properties of waste lubricated oil

Properties	Test Result	
	New Oil	Wasted Oil
Density	0.872	0.861
Flashpoint, °C	218°C	159°C
Fire point, °C	230°C	194°C
Rotational Viscometers at 135°C	27 Cp	13 Cp

2.3 Preparation of samples

In preparation for tests, mix WLO with asphalt binder.

1. The clean samples are heated to 150 degrees Celsius before being placed in test tubes.
2. In preparation for tests, perform initial assessments on the asphalt binder before mixing with WLO.
3. First, add the waste lubricating oil and record the basic results of the virgin asphalt.
4. After adding the WLO, heat the fresh sample and pour it into five different test tubes.
5. Add the WLO in different percentages (0%, 3%, 6%, 9%) by weight of bitumen.
6. Begin mixing the collected material, asphalt, and waste lubricant oil at a fixed speed of 1000 rpm for 5 minutes.

2.4 Asphalt testing

2.4.1 Penetration test

A typical needle will penetrate a tenth of a millimeter into an asphalt or mastic sample when subjected to 25°C, 100-gram load, and 5 seconds of load duration [16].

2.4.2 Softening point test (Ring & Ball test)

The Ring & Ball technique refers to the phenomenon where a 3.5-gram steel ball descends 25.4 millimeters (1 inch). It indicates the propensity to flow when heated to a higher temperature. Starting at 4 degrees Celsius of water, the test increases in temperature at a rate of 5 degrees Celsius per minute. We used ASTM D-36 to determine the validity of the test, this is a necessary test that helps in choosing the appropriate asphalt for different applications and knowing the degree of immersion and melting to ensure the quality of asphalt roads in the long term [17].

2.4.3 Flash and fire point

The Cleveland open cup tester's typical test procedure for flash and fire points defines a material's flash point as the lowest temperature at which a test flame ignites its vapors. The test flame must ignite the material at the ardor point for at least five seconds. This is a critical safety test to assess the asphalt's readiness to ignite under normal use conditions [18].

2.4.4 Rotational viscometer

Industry and construction frequently use a Rotational Viscometer (RV) to measure the viscosity of bitumen at high temperatures. We use the formula to create a super pave Performance Grade (PG) for asphalt binder.

$$\text{Viscosity in } 135^{\circ}\text{C} \leq 3 \text{ Pa} \cdot \text{s (Pascal-seconds)}$$

When doing the SuperPave PG bitumen specification test, it is most effective to execute it at a temperature of 275°F (135°C). This temperature aids in estimating the asphalt's ability to flow and perform under typical conditions [19].

2.5 Temperature susceptibility

It's defined as the rate at which a given bitumen's viscosity changes with temperature (or another measure of asphalt consistency). There have been numerous proposals and applications of such parameters for asphalt cement with varied amounts of WLO.

2.5.1 Penetration index

The temperature susceptibility is identified by the penetration index (PI). Higher values indicate lower TS, which links the softening point of binders and their penetration at 25 degrees Celsius. In the Shell Bitumen Handbook [20], a traditional way of PI measurement is shown with the following equation.

$$PI=\frac{1952-500*loglog\ (pen25)\ -20*TSP}{50*loglog\ (pen25)\ -TSP-120} \quad (1)$$

where,

Pen 25 = Penetration rate at 25, ℃.

Tsp= Temperature of softening point, ℃.

2.5.2 Penetration viscosity number

The penetration viscosity number (PVN) practically relates the penetration at 25℃ to the kinematic viscosity at 135℃; This restriction is provided to define how temperature affects asphalt. McLeod states that an upper PVN indicates less sensitivity to temperature than a lower PVN between the limits of -2.0 and 0.5 [20]. This equation is a representation of the PVN formula:

$$PVN=\frac{(1.5log\mu@135+1.19511\ logP@25-6.378)}{(0.79511-0.1858\ logP@25)} \quad (2)$$

where,

μ@135= Kinematic viscosity at 135℃, CST.

P@25= Penetration at 25℃, 1/10mm.

2.5.3 Temperature of equivalent stiffness (TES)

This indicates the temperature at which the asphalt cement has a stiffness modulus of 1.3810 N/m^2 after 2.8 hours of loading. Higher values indicate a higher Temperature susceptibility (TS) [20].

2.5.4 Stacked plot

The optimal ratio of the additive is shown by the graph that appeared and its values across multiple using the MDS chart. The data is clearly represented, and each category stacks up individually on the overall impact percentage, with each category's contributors seeing that impact. This appears partly due to its ability to compare clear proportions between different groups [21].

3. RESULT AND DISCUSSION

Figures 1-6 illustrate how WLO concentration affects the rheological characteristics of asphalt cement. Increasing WLO content in bitumen confirms increases in penetration values while increasing WLO concentration leads to a decrease in specific gravity, Specific gravity has an impact on asphalt's properties and performance. Asphalt with a high specific gravity improves its resistance to abrasion and cohesion, whereas a low one has benefits such as lightness and thermal expansion, and each has its applications. Increasing WLO content in bitumen confirms decreased flash and fire points. Knowing asphalt's melting and freezing points is important for safety; decreased kinematic viscosity is critical for the asphalt mixture's cohesion and adhesion; and decreased softening points. This is critical for ensuring the long-term quality of asphalt roads. A high-elastic network modifies the viscosity and stiffness compared to virgin asphalt (0% WLO concentration). Nevertheless, as WLO content increases, the impact on ductility is negligible. We measured the kinematic viscosity at 135℃ and 160℃. Figure 7(a-b) illustrates that when temperature variance increases, kinematic viscosity decreases. Figure 2 illustrates the influence of WLO on the degree of penetration that increases the permeability of bitumen, and the best-added ratio is 6% to give the best permeability value (40-50), conforming to the resident engineer's manual for construction projects. Cold zones use soft asphalt with high penetration. Table 3 displays the results of adding WLO to bitumen. Figures 8-10 illustrate when the increase in WLO concentration on bitumen by weight decreases the parameter index of temperature susceptibility of modified asphalt cement, which means a higher susceptibility of modified asphalt to temperature. Figure 11 illustrates optimal ratio of the additive is shown by the graph that appeared and its values across multiple using the Stacked Plot. The result of adding WLO to bitumen is shown in Table 3, and the effect of adding WLO to bitumen in parameters of Temperature susceptibility is shown in Table 4.

Table 3. Effect of adding different percentages of WLO on bitumen properties

Properties	ASTM Specification	Modified Asphalt		
		3%	6%	9%
Penetration	“ASTM D-5”	35	40	58
Softening point	“ASTM-36”	55	52.5	49
Ductility	ASTM D-113	115	105	80
Specific gravity	ASTM D-70	1.055	1.043	1.042
Flash point	ASTM D-92	280	275	270
Fire point	ASTM D-92	295℃	293℃	283℃
Viscosity	135℃, Cp	1306.5Cp	1006.5Cp	743.75Cp
	160℃, Cp	400Cp	331Cp	250Cp

Table 4. Temperature susceptibility parameters of modified asphalt cement

Modified Asphalt	PI	PVN	TES
0	-.079	-2.5	17
3%	-0.83	0.22	17.3
6%	-1.2	0.013	18,5
9%	-1.25	0.003	18.9

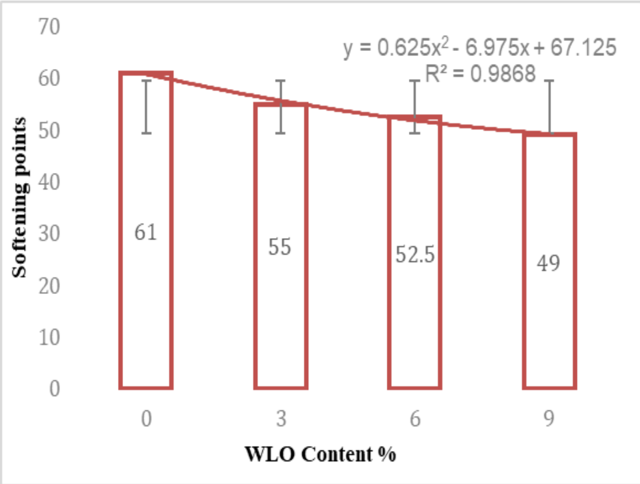

Figure 1. The impact of WLO concentration on bitumen softening points

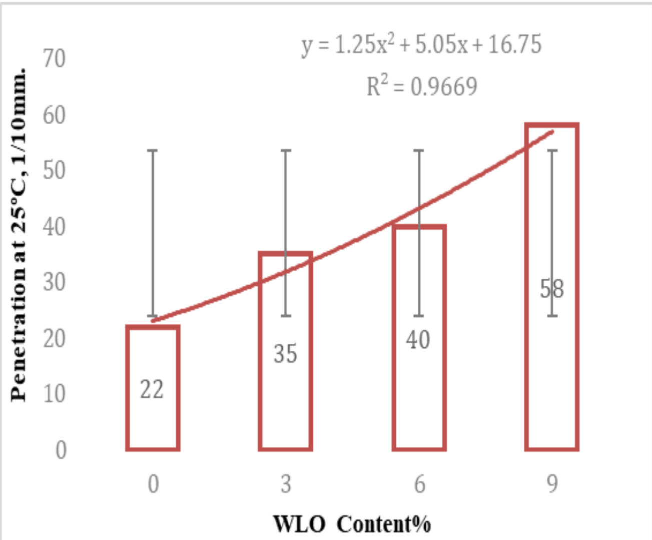

Figure 2. The impact of WLO concentrations on bitumen penetration

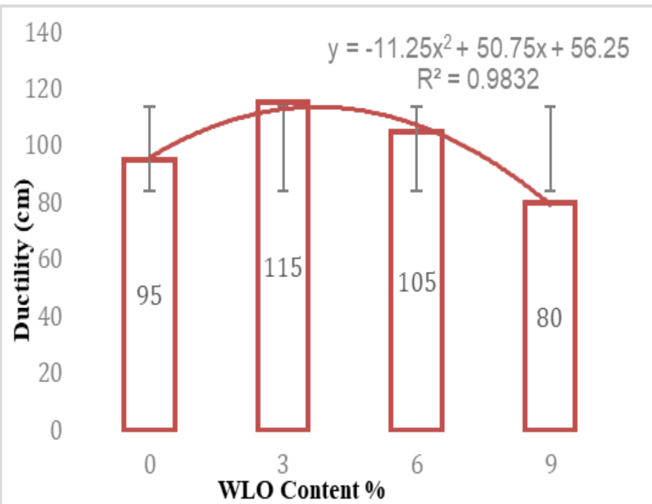

Figure 3. The impact of WLO concentrations on bitumen ductility

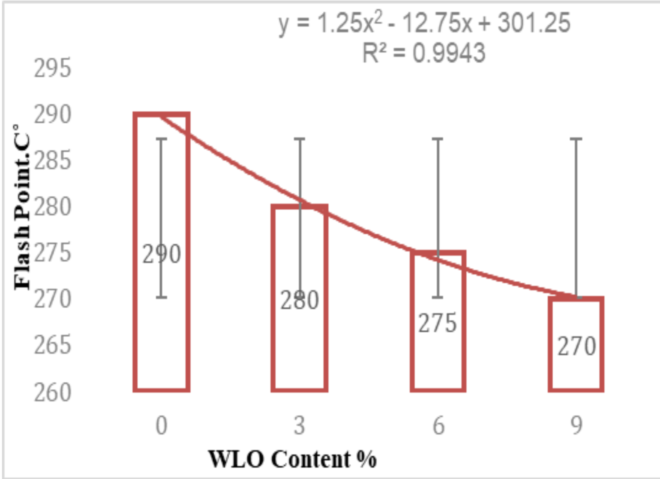

Figure 4. The impact of WLO concentrations on bitumen flash points

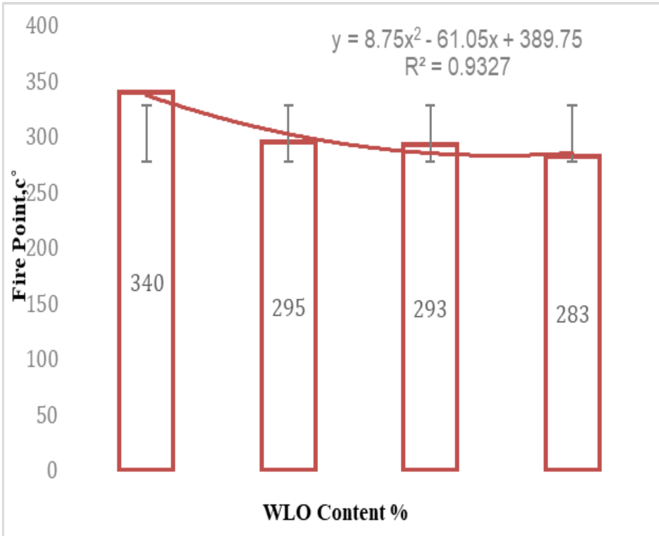

Figure 5. The impact of WLO concentrations on bitumen fire points

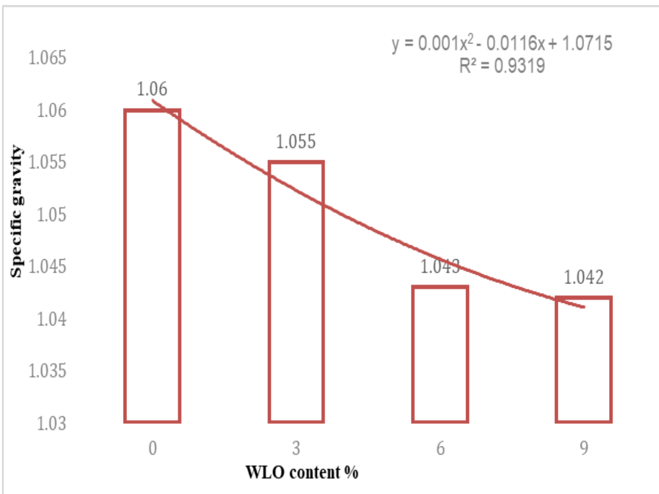

Figure 6. The impact of WLO concentrations on bitumen specific gravity

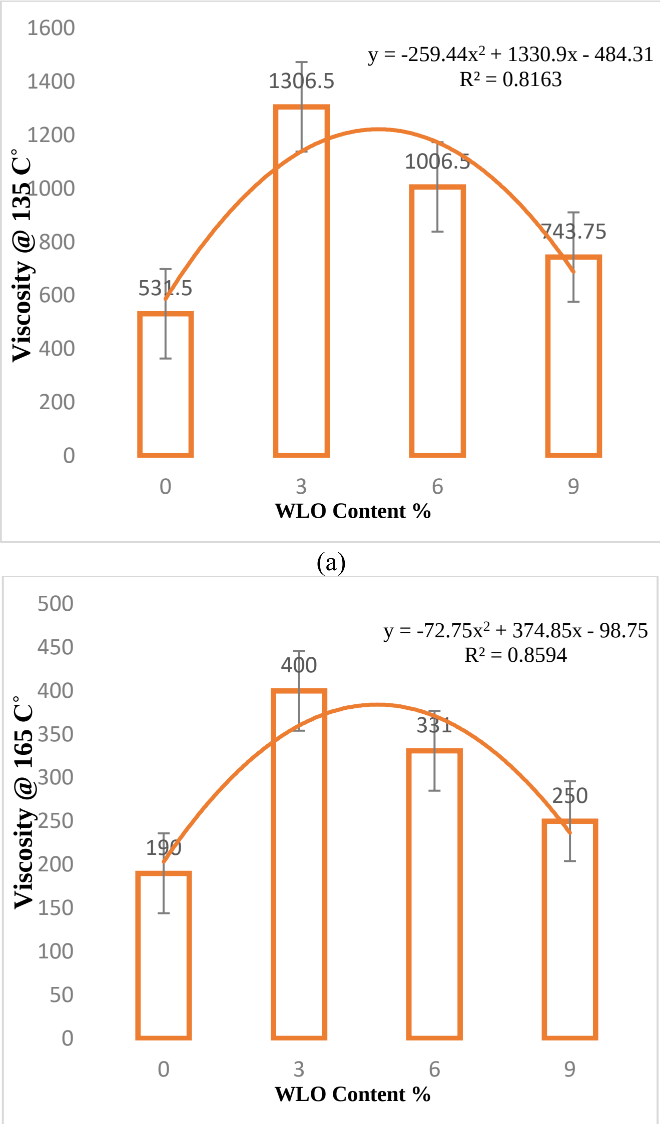

Figure 7. (a) The impact of WLO concentration on bitumen viscosity @ 135℃, (b) The impact of WLO concentration on bitumen viscosity @ 160℃

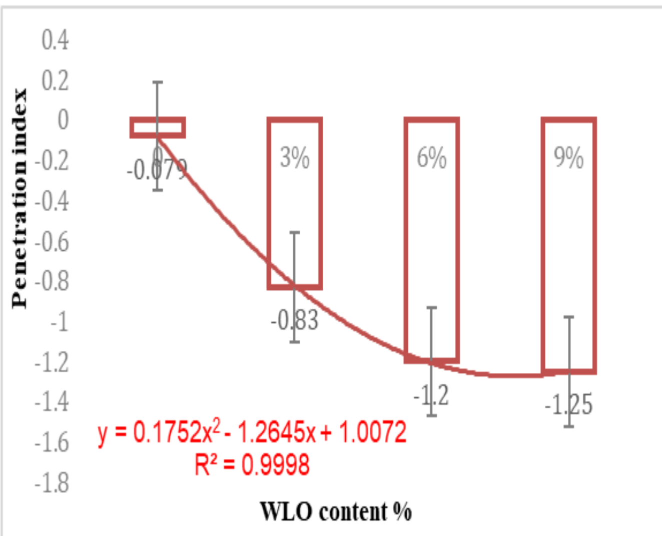

Figure 8. The impact of WLO concentration in (PI) of bitumen

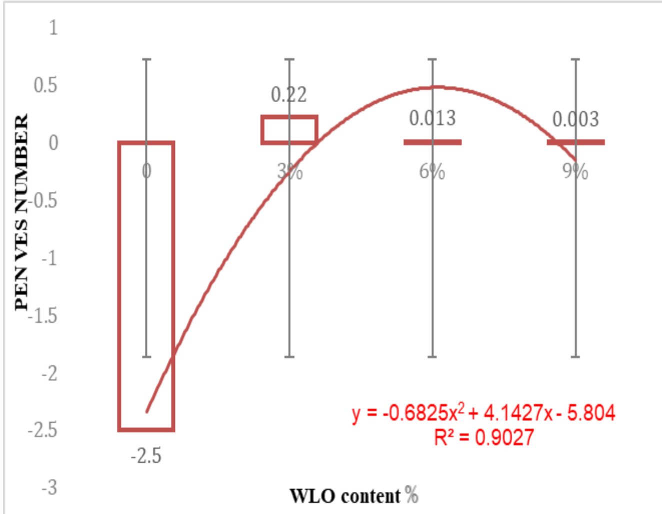

Figure 9. The impact of WLO concentration in (PVN) of bitumen

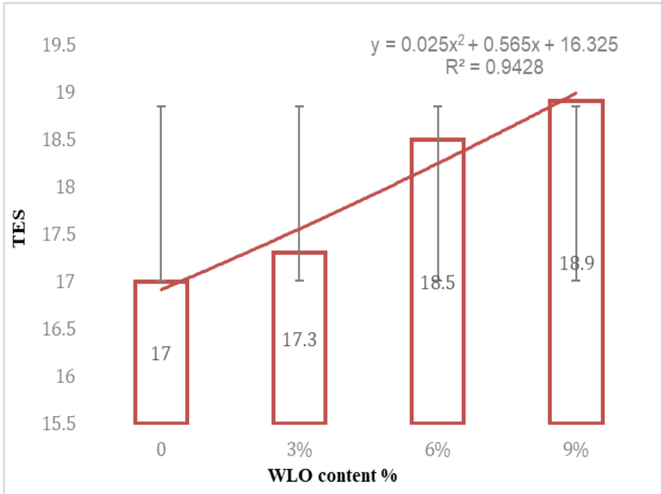

Figure 10. The impact of WLO concentration in (TES) of bitumen

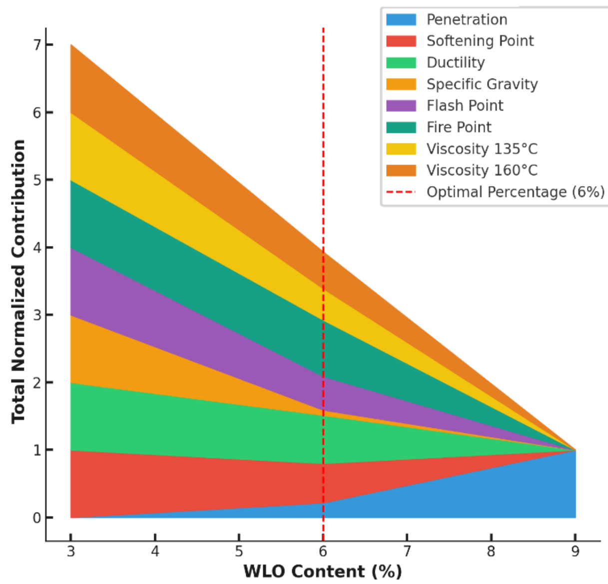

Figure 11. Finding the optimal modification ratio based on the common contribution of all properties

4. CONCLUSION

This research investigated the properties of mixed bitumen with blended waste lubricating oil for applications in flexible pavements. The investigated properties include the basic gravity, ductility, viscosity at two temperature penetration, flash and fire point, and softening point of the modified bitumen. The conclusions of the research will be as follows:

(1) Replacing bitumen with WLO decreases the specific gravity and the resultant binder's softening point, viscosity, flash and fire point. However, the bitumen penetration value increased after replacement with WLO.

(2) WLO added to virgin bitumen at 3%, 6%, and 9% resulted in increased penetration and bitumen hardness and adhesiveness, with a decrease in penetration testing with decreasing WLO.

(3) Increasing bitumen durability at high temperatures by raising the softening point while lowering the WLO concentration.

(4) Increase the rutting resistance due to the increasing viscosity as the WLO concentration decreases; boost the WLO material's safety as the flash point decreases as the WLO content rises but is still greater than the critical temperature within the pug mill.

(5) According to the findings, modified bitumen with WLO has a higher temperature susceptibility than pure bitumen since its penetration index, penetration viscosity number, and TES are lower than pure bitumen.

(6) The optimum ratio is the ratio that achieves a balance between the rheological properties of asphalt. achieves a balance between hardness and softness through the penetration test and softness point, and achieves the best resistance to deformation with the highest viscosity at high temperatures and the best flexibility and crack resistance performance. Based on the preceding discussion and as shown in Figure 11, the addition of 6% WLO provides the best performance. This composition not only offers optimal resistance to deformation and the necessary flexibility for use under varying climatic and traffic conditions but also meets the Iraqi standards for road and bridge materials.

(7) This is consistent with previous studies where it was institute that adding used engine oil to bitumen increases the penetration value and decrease the softening point. Also, the viscosity and resistance of bitumen to high temperatures decrease with increasing oil concentration. Still, on the other hand, its flexibility and resistance to cracking at low temperatures increase and vary with the optimum ratio of asphalt that's meet the requirements of the Iraqi standards for road and bridge materials [22, 23].

(8) Substantially modified asphalt with WLO shows higher sensitivity to high temperatures due to its increased softness, which makes it less stable at high temperatures but more flexible in the flexible pavement, especially in low-temperature conditions.

(9) These results confirm the importance of using waste materials in asphalt paving applications, as they provide environmental and economic benefits and contribute to environmental sustainability.

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