Performance Evaluation of Different Aged Binder Modified With Waste Cooking Oil And Waste Engine Oil

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Thesis Supervisor: Dr. Arshad Hussain

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

VB	Virgin Binder
AB	Aged Binder
WCO	Waste Cooking Oil
WEO	Waste Engine Oil
AB-C1	Aged Binder with 1% Waste Cooking Oil
AB-C2	Aged Binder with 2% Waste Cooking Oil
AB-C3	Aged Binder with 3% Waste Cooking Oil
AB-C4	Aged Binder with 4% Waste Cooking Oil
AB-C5	Aged Binder with 5% Waste Cooking Oil
AB-E1	Aged Binder with 1% Waste Engine Oil
AB-E2	Aged Binder with 2% Waste Engine Oil
AB-E3	Aged Binder with 3% Waste Engine Oil
AB-E4	Aged Binder with 4% Waste Engine Oil
AB-E5	Aged Binder with 5% Waste Engine Oil
WO	Waste Oil

ABSTRACT

The performance evaluation of various aged binders changed with Waste Cooking Oil (WCO) and Waste Engine Oil (WEO) encompasses a comprehensive investigation into the effects of short-term and long-term aging on binder properties. Short-term aging typically mirrors the immediate changes experienced by binders upon production, while long-term aging entails prolonged openness to environmental factors, simulating real-world conditions. Through thorough testing procedures including penetration, softening point, pliability, flash point, and thickness tests, the review examines the evolution of binder characteristics after some time, elucidating the impact of aging and modification with WCO and WEO. Perceiving the research gap encompassing broadened long-term aging, this study embarks on an exploration of binder behavior beyond conventional aging durations. By broadening the aging time frame, the research aims to uncover nuanced bits of knowledge into the durability and performance of changed binders, making up for a critical shortcoming in momentum asphalt and pavement engineering literature. Through systematic analysis and comparison with short-term and long- term aged binders, the review looks to elucidate the transformative effects of extended long-term aging on binder properties, revealing insight into optimal modification strategies and enhancing the sustainability and versatility of asphalt pavements. This endeavor vows to contribute significantly to the advancement of asphalt binder innovation, paving the way for more strong and environmentally conscious infrastructure solutions. In this review, an investigation was conducted to determine the optimal proportions of waste cooking oil and waste engine oil for short-term, long-term, and extended long-term aging of bitumen. The research included aging bitumen samples throughout a period of time ranging from 5 to 17 hours with 3-hour intervals, allowing for a comprehensive assessment through conventional tests and rheological analyses. By systematically varying the percentages of waste cooking oil and waste engine oil, the review aimed to pinpoint the best combination for enhancing bitumen aging characteristics. The obtained results from these tests educated the selection regarding ideal percentages, directing further analysis in terms of chemical composition and minuscule properties for a careful evaluation of expanded long-term aged asphalt. Consequently, chemical analysis and infinitesimal examinations were performed to dive further into the effects of the chose waste oil percentages on the lengthy long-term aging of asphalt. The chemical analysis aimed at recognizing molecular changes and the overall composition of the aged asphalt, revealing insight into potential alterations in its structural uprightness. Concurrently, minuscule analysis allowed for a detailed investigation of the asphalt's microstructure, giving bits of knowledge into the impact of waste cooking oil and waste engine oil on the formation of microcracks, aggregates, and other relevant features. This consolidated approach allowed for a comprehensive understanding of the impact of waste oil incorporation on the drawn out extended long-term aging of asphalt, contributing valuable experiences to the field of asphalt materials and sustainable waste utilization.

Keywords: Performance Evaluation, Asphalt Aging, Waste cooking oil, Waste engine oil, Asphalt durability, Sustainable Modification, Extended Long-term Aging.

CHAPTER 1: INTRODUCTION

1.1 Background

Asphalt, occasionally referred to as bitumen, is a heavy, gummy material made from petroleum that is crucial to the infrastructure and building industries. Bitumen, the heaviest component of the oil, is a dense and sticky substance that is produced during the distillation of crude oil. It is made up of a mixture of organic and hydrocarbon substances. Its high viscosity, one of its distinguishing qualities, contributes to its usefulness in construction applications. Due to its remarkable adhesive qualities, it is a crucial binding agent for aggregates in asphalt, which is the main component of road paving. This quality guarantees the durability and stability of roads, allowing them to withstand the demands of traffic. Additionally, bitumen's wet-resistance makes it a crucial component for roofing materials like asphalt shingles that successfully protect buildings from water penetration.

The age of the asphalt binder is one of the crucial characteristics that distinguishes a reclaimed asphalt blend from a fresh one. The alterations in asphalt pavement characteristics that take place soon after installation and construction are referred to as short-term aging of asphalt. The asphalt binder's exposure to environmental elements like sunlight, temperature changes, and atmospheric oxygen is the main cause of this aging process. The volatile components in the binder begin to evaporate as the asphalt pavement is exposed to these circumstances, gradually increasing the viscosity and stiffness of the binder. As a result, the pavement may become less flexible and crack. Due to the loss and conversion of volatile components (such as maltenes) into less volatile components (such as asphaltenes) as the asphalt ages, the binder loses its viscoelastic qualities, making the pavement material stiffer, brittle, and more prone to cracking **[1].** The portion of bitumen with a greater molecular weight and polarity is known as asphaltenes. Carbon, hydrogen, oxygen, nitrogen, and sulfur make up the complex molecules that make them up. Bitumen's viscosity and black color are both caused by asphaltenes. They aid in holding the particles in asphalt mixes together and assist bitumen's binding capabilities. The portion of bitumen with a lower molecular weight and less polarity is called maltenes. They are made up of a combination of organic molecules and hydrocarbons. Bitumen's fluidity and functionality, which make it more facile to work with during mixing and building, are due to maltenes.

When referring to asphalt, rejuvenation is the process of refurbishing the aging or discarded characteristics of the pavement. This is frequently done to diminish the impacts of temporary aging and increase the life expectancy of the pavement. The process of rejuvenating asphalt usually entails coating the pavement's surface with specialized manufacturers ingredients or treatments. These substances have the ability to permeate the asphalt binder and alter its physical characteristics, aiding in the reversal of oxidation & volatilization caused by age. This study examines the rheological, chemical, and microscopic aspects of employing waste engine oil and waste cooking oil as a rejuvenator to modify the aged binder.

1.2 Problem Statement

The pervasive challenge of aging phenomena in asphalt rehabilitation underscores the need for effective strategies, prompting this thesis to investigate the mitigation of aging effects through the application of rejuvenating agents.

1.3 Research Objectives

The objectives of this research are as follows:

- Evaluate the effectiveness of Waste Oils as rejuvenating agents in different aged asphalt binder.
- Chemical analysis of aged asphalt binder using FTIR.
- Microscopical Analysis of aged asphalt binder using SEM.

1.4 Scope of the Research

The ecologically sound utilization of natural resources is fundamentally related to research effort. To recover the qualities of an aged binder, the study mainly focusses on using waste materials. This study primarily compares modified bitumen to virgin bitumen and examines the best percentage of waste oils for aged asphalt. The details of tests are shown in the following table 1-1.

Table 1.1: Test Matrix

Aged Asphalt	**Tests**	**VB**	**WCO %**					**WEO %**					**TS**
			1 %	**2 %**	**3 %**	**4 %**	**5 %**	**1 %**	**2 %**	**3 %**	**4 %**	**5 %**	
5-Hours	Penetration	3	3	3	3	3	3	3	3	3	3	3	33
	Softening point	3	3	3	3	3	3	3	3	3	3	3	33
	Flash and Fire point	3	3	3	3	3	3	3	3	3	3	3	33
	Viscosity	3	3	3	3	3	3	3	3	3	3	3	33
8-Hours	Penetration	-	3	3	3	3	3	3	3	3	3	3	30
	Softening point	-	3	3	3	3	3	3	3	3	3	3	30
	Flash and Fire point	-	3	3	3	3	3	3	3	3	3	3	30
	Viscosity	-	3	3	3	3	3	3	3	3	3	3	30
11-Hours	Penetration	-	3	3	3	3	3	3	3	3	3	3	30
	Softening point	-	3	3	3	3	3	3	3	3	3	3	30
	Flash and Fire point	-	3	3	3	3	3	3	3	3	3	3	30
	Viscosity	-	3	3	3	3	3	3	3	3	3	3	30
14-Hours	Penetration	-	3	3	3	3	3	3	3	3	3	3	30
	Softening point	-	3	3	3	3	3	3	3	3	3	3	30
	Flash and Fire point	-	3	3	3	3	3	3	3	3	3	3	30
	Viscosity	-	3	3	3	3	3	3	3	3	3	3	30
17-Hours	Penetration	-	3	3	3	3	3	3	3	3	3	3	30
	Softening point	-	3	3	3	3	3	3	3	3	3	3	30
	Flash and Fire point	-	3	3	3	3	3	3	3	3	3	3	30
	Viscosity	-	3	3	3	3	3	3	3	3	3	3	30
Total Samples		12	60	60	60	60	60	60	60	60	60	60	612

Chemical Tests			**Grand Total Samples**
Material	**Test Name**	**Sample**	
Virgin Asphalt	Fourier transform infrared (FTIR) spectroscopy	1	
17-hr Aged Asphalt		1	
Modified Asphalt		1	
Chemical Tests			
Material	**Test Name**	**Sample**	
17-hr Aged Asphalt	Scanning Electron Microscopy (SEM)	1	
Modified Asphalt		1	**617**

1.5. Thesis Organization

Chapter 1 introduces the significance and contributions of using waste oils as rejuvenating agents in aged binders, particularly in the field of Civil Engineering with an emphasis on transportation engineering. It highlights the economic benefits of utilizing waste materials and discusses the relevance of this research, its potential contributions, and outlines the study's objectives.

Chapter 2 presents a literature review emphasizing the importance of improving asphalt binder performance in pavement construction. It highlights the potential of waste cooking oil and waste engine oil as sustainable modifiers that address binder aging while offering environmental benefits. The use of these waste materials supports the creation of durable, eco-friendly pavements, and as research advances, their integration may play a key role in enhancing both performance and sustainability in asphalt pavement engineering.

Chapter 3 outlines the research methodology used to explore the relationship between bitumen grade 60–70, aging, and the addition of waste cooking oil (WCO) and waste engine oil (WEO). The study begins with aging bitumen through the Thin Film Oven Test (TFOT) for various durations, followed by adding waste oils in proportions ranging from 1% to 4%. Standard tests such as penetration, softening point, ductility, flash point, and fire point are conducted to determine the optimal oil content at different aging stages. Advanced techniques, including viscosity testing, Fourier transform infrared (FTIR) spectroscopy, and scanning electron microscopy (SEM), are then used to assess the rheological, molecular, and microstructural changes caused by waste oil treatment. The goal is to provide critical insights for creating durable, sustainable asphalt mixtures suitable for road construction, highlighting the potential of these findings to advance eco-friendly infrastructure.

Chapter 4 presents the results obtained using the methodologies described in Chapter 3. It includes tables and graphs to illustrate the findings and discusses how waste oils impact the properties of aged binders

Chapter 5 presents the conclusions of the study and its contributions to the field of pavement maintenance. It briefly reviews the research objectives outlined in Chapter 1 and assesses whether they were successfully achieved."The overall methodology is shown in figure 1.

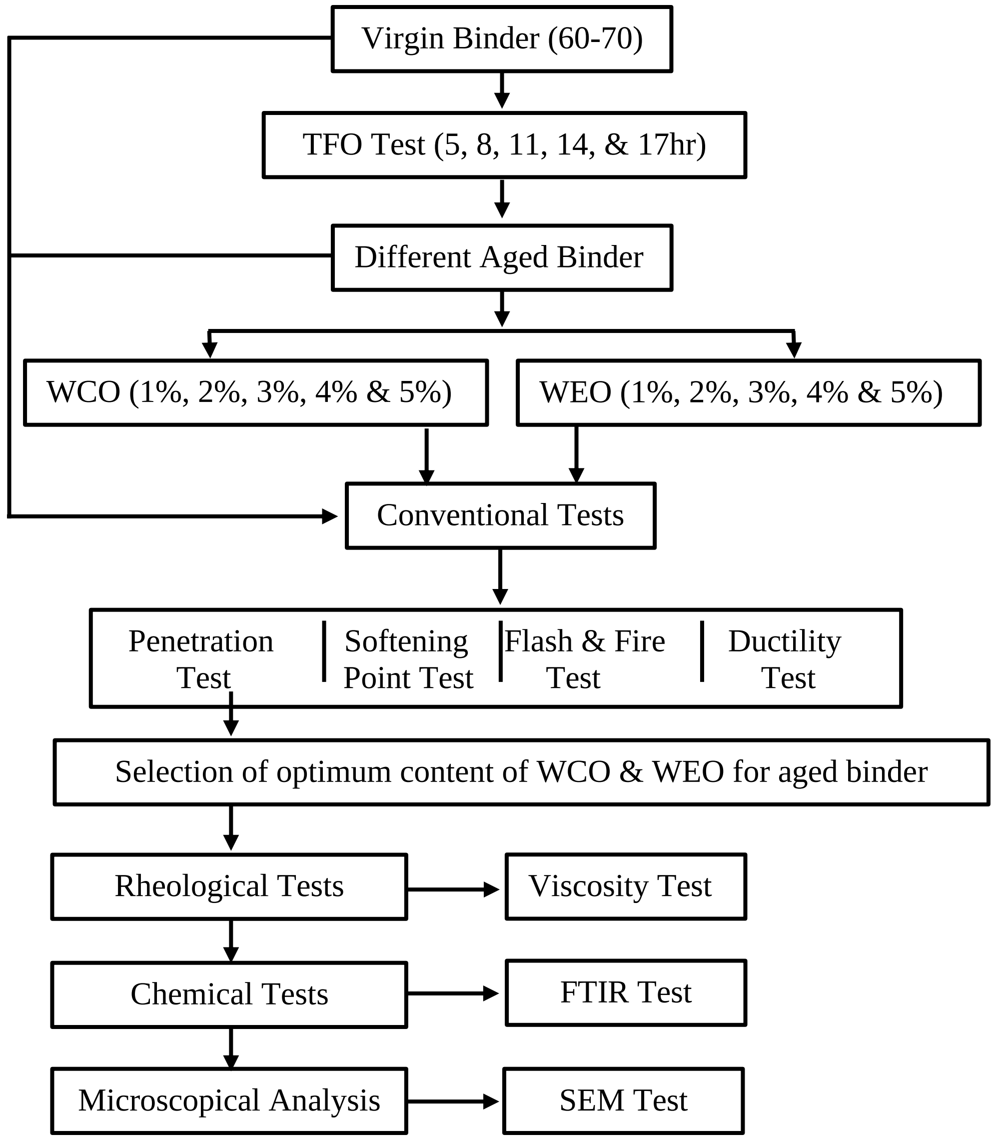


Figure 1: Graphical Representation of Research Methodology

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Transportation by road plays a vital role in the country's economy. Road network provide access across different part of the country which ultimately increase the potential of providing access to different market across the country. Bitumen is a hydrocarbon which is widely use in road construction as a binder across the world. Bitumen is petroleum by-product. About 83 thousand. Metric ton of bitumen is consumed every year. Out of this amount about 70% of bitumen is use for road construction. Analysis shows that through 2019, global demand for asphalt is projected to expand 2.8 percent per year to 122.5 million metric tons (742.5 million barrels). Such an increasing demand of bitumen let researchers explore alternative ways to reduce the usage of bitumen in road industry.

2.2 Flexible payment

Flexible payments comprise an urgent component of our transportation framework, flawlessly working with the development of vehicles while persevering through the difficulties presented by fluctuating burdens and ecological circumstances. This thorough aide means to dive profoundly into the mind-boggling layers of adaptable asphalts, disentangling their structure, capabilities, and the subtleties associated with their development. By acquiring a significant comprehension of these layers, we furnish ourselves with the information expected to settle on informed choices in the plan and execution of strong and versatile adaptable asphalt frameworks. The surface course, likewise alluded to as the wearing course, remains as the cutting-edge fighter, straightforwardly captivating with the determined powers forced by vehicular traffic. It goes past being a simple defensive safeguard; it is a refined mix of top-notch totals and thick bitumen or black-top. The meaning of the surface course lies in its capacity to oppose wear as well as in its job as a supporter of slip opposition, contact, and compelling seepage.

In this layer, water snugness against surface water penetration is foremost, requesting fastidious thoughtfulness regarding material choice and development rehearses. Digging into the complexities of the surface course uncovers a unique domain where the thickness, for the most part going from 25 to 50 mm, is a basic boundary. Following the surface course, the binder course emerges as a key player in the load transfer mechanism within the pavement system. Constructed using aggregates and bitumen, the binder course operates at a slightly lower quality than its surface counterpart. However, its role in seamlessly transferring the loads from the surface course to the base course is indispensable. The binder course offers a strategic bridge, ensuring that the forces exerted by vehicular traffic are distributed with precision. The thickness of the binder course, typically ranging from 50 to 100 mm, adds another layer of complexity to the pavement's composition.

The base course expects an essential job in supporting the primary respectability of the flexible asphalt. It goes about as the mediator layer, effectively conveying the heaps from the upper layers to the hidden subbase and subgrade layers. The development of the base course includes the utilization of hard and tough totals, which might be settled, granular, or a blend of both. The thickness of the base course turns into a basic boundary, with a suggested least thickness of 100 mm. This layer, while frequently ignored, structures the foundation of the asphalt structure, underlining the requirement for cautious thought of material properties and layer thickness.

Situated underneath the base course, the subbase course reflects the elements of its prevalent partner. Nonetheless, its need is dependent upon the strength of the subgrade soil. In cases where the sub-grade soil shows vigor, the subbase course might be considered superfluous. Nonetheless, for more vulnerable sub-grade soils, a base thickness of 100 mm is suggested for the subbase course. The development materials shift to granular totals, disentangling an interesting exchange of geotechnical contemplations and burden dissemination elements.

At the actual center of the flexible asphalt structure lies the subgrade — a layer that fills in as the establishment for the whole framework. Containing compacted normal soil, the subgrade goes through fastidious compaction to a predetermined profundity, typically going from 150 to 300 mm. This layer's main role is to get the heaps exuding from the upper layers and, thusly, convey them actually. The subgrade's solidarity is a basic element, with the burdens from the upper layers requiring cautious regulation inside the subgrade's ability. The specialty of compacting the subgrade reveals a domain where geotechnical designing fulfills the needs of transportation framework.

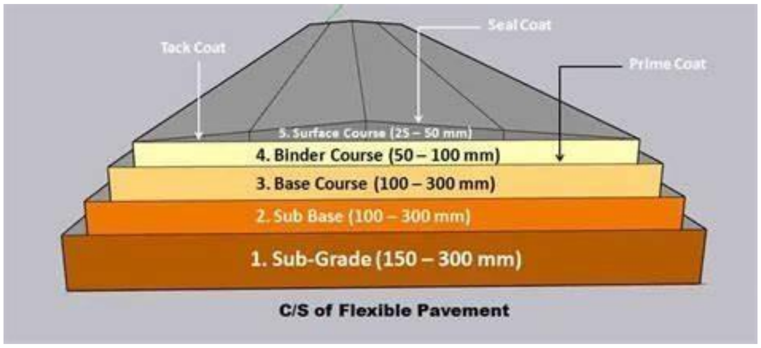


Figure 1.1: Flexible payments

2.3 Bitumen

Bitumen, a viscous, black, and sticky material derived from crude oil distillation, serves as a crucial binder in the construction of roads, highways, and infrastructure projects. Also called asphalt consists of different fractions, including the polar and high molecular weight asphaltenes, as well as the less polar and lower molecular weight maltenes. These fractions play a crucial role in determining the rheological and chemical properties of asphalt. Understanding the chemical composition and behavior of these fractions is essential for comprehensively characterizing asphalt [2]. Similarly, classified by viscosity, measured through penetration tests, bitumen properties can be enhanced with additives such as polymers and waste oils. As the linchpin of asphalt pavements, asphalt binders, derived from crude oil, bind aggregate particles together, ensuring pavement durability amid environmental stressors like temperature changes, heavy traffic, and UV radiation. Researchers and engineers constantly innovate to improve asphalt binder performance and extend pavement lifespan, recognizing its pivotal role in road safety and longevity [3].

2.4 Aging of Asphalt Binders

The aging process of asphalt binder encompasses a multifaceted array of physical, chemical, and rheological changes influenced by environmental exposure and traffic loading. Oxidation, volatilization, hardening, and altered aggregate adhesion contribute to increased stiffness, decreased flexibility, and modified bonding properties. Rejuvenation techniques, such as the addition of rejuvenators like waste cooking oil, aim to restore asphalt binder properties by rebalancing asphaltene and maltene components, thus enhancing performance and durability. Understanding aging mechanisms is pivotal for devising effective strategies to counter aging effects and optimize asphalt pavement longevity [4]**.** Similarly, another research delves into the aging effects on asphaltene and maltene fractions, highlighting substantial compositional shifts pre- and post-aging. Aging induces heightened carbonyl and sulfoxide signals; alongside minor aromaticity increases in bitumen samples. Post-aging, asphaltene fractions notably exhibit escalated carbonyl and sulfoxide signals, suggesting insoluble molecule formation due to oxygen reaction, leading to increased polarity in asphaltenes and alterations in molecular weight as per GPC measurements. Moreover, aromaticity amplifies in asphaltenes post-aging, contrasting with maltenes' unaffected aromaticity levels [5].

2.5 Waste cooking oil as modifier

Waste cooking oil (WCO), a residual product of cooking processes, emerges as a promising rejuvenating agent for bitumen, its properties contingent upon the oil type and cooking methods employed. Comprising diverse fatty acids like lauric acid, myristic acid, and oleic acid, WCO's composition varies with its source and may undergo viscosity and density fluctuations due to temperature and impurities. Despite potential chemical alterations from cooking exposure, WCO, if improperly disposed, poses environmental risks but serves as an eco-friendly alternative when repurposed for bitumen rejuvenation. In the study, WCO demonstrated its efficacy as a rejuvenating agent for aged bitumen, enhancing its rheological and physical properties, mimicking those of the original bitumen.

Augmented penetration index suggests reduced temperature susceptibility and more elastic behavior, with WCO curbing short-term aging tendencies, rendering aged bitumen akin to virgin quality. By repurposing WCO, the study not only addresses waste management concerns but also offers a cost-effective solution for highway renovation, underlining its potential to enhance bituminous material performance and extend service life in an environmentally sustainable manner [6].

2.6 Waste engine oil as modifier

Waste oil is characterized as any oil based or synthetic oil that, through pollution, has become unsatisfactory for its unique reason because of the presence of pollutants or loss of unique properties. The physical and chemical characteristics of waste engine oil (WEO) are shaped by its original properties and the environmental conditions encountered during its service life. WEO displays varied physical attributes such as pour point, density, specific gravity, flash and fire points, and percentage loss on heating, transitioning between semi-solid and liquid states depending on temperature and demonstrating lower density and specific gravity values compared to water. Its combustible nature is quantified by flash and fire points, while the percentage loss on heating indicates volatiles. Chemically, WEO harbors contaminants like heavy metals requiring adherence to safer reuse limits when blended with asphalt. Refinement, or re-refining, of WEO involves chemical, physical, and solvent extraction processes to tailor it for reuse. Chemical and physical evaluations assess WEO properties before reuse. Incorporating WEO into asphalt mixtures enhances their performance, bolstering rutting resistance and overall functionality, particularly in mixtures with reclaimed asphalt pavement, influencing aged binder wettability. Nonetheless, comprehensive evaluation of processed WEO and asphalt binder source, usage history, composition, and physical properties is imperative to determine optimal usage levels in asphalt mixtures. While reusing WEO in asphaltic materials presents a sustainable solution for waste management and potential performance improvements, compatibility between WEO properties and asphaltic material performance must be ensured for effective utilization [7].

2.7 Level of research already carried out

Conducts a broad assessment of bitumen's compound sythesis, especially its asphaltene and maltene portions, both pre and post long-term maturing. Using Fourier transform infrared spectroscopy (FTIR), nuclear magnetic resonance spectroscopy (NMR), season of flight - optional particle mass spectrometry (TOF-SIMS), and gel permeation chromatography (GPC), the review depicts shifts in bitumen sythesis. It highlights contrasts in substance cosmetics somewhere in the range of asphaltene and maltene parts, as well as the maturing actuated modifications, including expanded carbonyl and sulfoxide signals inside the asphaltene division post-maturing, implying insoluble atom arrangement from oxygen response. Also, it notes expanded aromaticity and changes in atomic weight, giving bits of knowledge into sub- atomic level transformations during maturing. The discoveries clarify huge changes in bitumen's compound piece because of maturing, offering urgent experiences into its exhibition suggestions in viable applications and developing understanding of bitumen's maturing cycle and substance modifications for experts and specialists in the field [5].

Makes sense of that bitumen goes through maturing during stockpiling, blending, transport, and laying out and about, as well as during its administration life. This maturing system can prompt a decrease in the physical and rheological properties of the bitumen, which can adversely affect the exhibition of asphalts. The motivation behind utilizing waste cooking oil (WCO) as a restoring specialist is to give a harmless to the ecosystem answer for this issue. WCO is a waste material that dirties landfills and waterways, and its utilization as a reviving specialist can assist with diminishing this contamination while likewise working on the exhibition of bitumen in asphalts. The investigation discovered that utilizing 3-4% of WCO can revive matured bitumen to a condition that intently looks like the physical and rheological properties of the first bitumen. This revival is accomplished by lessening the proportion of asphaltenes to maltenes in the bitumen, which prompts an expansion in the entrance esteem. The WCO likewise goes about as a cell reinforcement or rejuvenator on the age-solidified bitumen. The aftereffects of the review showed that the WCO revived bitumen tends to transient maturing contrasted with virgin bitumen. The physical and substance properties of the first bitumen, matured bitumen, and revived bitumen were estimated and looked at utilizing different bitumen cover tests, including relaxing point, entrance, Brookfield consistency, dynamic shear rheometer, and Fourier transform infrared spectroscopy. Generally speaking, the review shows the capability of utilizing waste cooking oil as a reviving specialist for matured bitumen, giving an earth and monetarily reasonable answer for the reuse of this waste material [6].

The strategy included the utilization of Gel Permeation Chromatography (GPC) to break down the dissemination of substances with various atomic loads in black-top fasteners. The black-top folios were changed with wasted cooking oil (WCO) and a cell reinforcement (168) to assess their consequences for aging opposition. The WCO was prepared by searing vegetable oil in the research facility, and the cell reinforcement 168 was utilized at a limited quantity (1% by weight). The particular advances remembered dissolving 20 mg of black-top fastener for tetrahydrofuran for 24 hours, trailed by GPC testing with a portable period of THF streaming at a speed of 1 mL/min at a section temperature of 40°C. The actual properties of the changed black-top fasteners were then assessed, including penetration, mellowing point, and pliability, to survey their high and low-temperature execution. The results uncovered that the expansion of WCO and 168 prompted gentler black-top folios with expanded flexibility, showing further developed low-temperature break opposition. Besides, the aging opposition of the black-top folios was fundamentally upgraded, as confirmed by the decrease in huge sub-atomic size (LMS) and the improvement in aging records, for example, pliability aging ratio (DAR) and penetration aging ratio (Standard). The review showed that the mix of WCO and 168 actually worked on the aging opposition of black-top fasteners, offering possible advantages for the longevity and execution of black-top asphalt [8].

This researcher potential reuse of waste engine oil (WEO) related to asphaltic materials, especially in the development and upkeep of asphalt foundation. The paper accentuates the significance of manageable practices in asphalt development and support, including the reusing of asphalt materials and the utilization of elective materials. It features the difficulties related with the utilization of reused black-top asphalt (RAP), especially the higher consistency of the folio inside RAP because of aging of hydrocarbon parts. This higher consistency can prompt functionality issues during development and execution issues, for example, rutting and weakness during the help life of the asphalt. Besides, the paper digs into the capability of waste motor oil as a reasonable material for use related to black-top folio. It examines the physical and compound properties of WEO, as well as the refining system engaged with preparing WEO for reuse. The expected advantages of integrating WEO into asphaltic materials, like critical reserve funds, preservation of normal assets, and decrease in energy utilization. It examines the different angles connected with the chance of integrating WEO into fastener and combination, as well as the difficulties and closing comments related with the utilization of WEO related to asphaltic materials [7].

In the review, the analysts researched the effect of waste cooking oil (WCO) and waste motor oil (WEO) on the actual properties of matured bitumen. The underlying changes included supplanting a part of the VG 40 bitumen with WCO and WEO at concentrations going from 1% to 5% by weight of the folio. The changed bitumen was made by physically blending WCO and WEO in with the VG 40 bitumen at 150°C until a moderately homogenous blend was framed. The actual properties of the adjusted bitumen were then assessed through different tests. The results uncovered that the expansion of WCO and WEO brought about expanded penetration esteems and decreased relaxing point temperatures under matured conditions contrasted with VG 40 bitumen. Also, the change prompted bitumen with lower consistency, and the utilization of up to 4% waste oil was found to ideally keep up with bitumen grade. Besides, the malleability of the changed covers expanded with the level of waste oil, showing further developed protection from breaking and temperature versatility. The penetration file additionally expanded with how much WCO and WEO utilized, recommending diminished temperature responsiveness and expanded hardness. These discoveries propose the capability of utilizing WCO and WEO to improve the functionality and execution of matured bitumen in expressway development, offering practical and productive answers for street framework [9].

2.8 Environmental Benefits of Waste Oil Adjustment

The consolidation of waste cooking oil and waste motor oil as modifiers in asphalt fasteners conveys huge natural advantages. Reusing these waste materials for development purposes lessens the dependence on virgin assets, subsequently decreasing the ecological effect related with customary asphalt folios. Additionally, by using waste cooking oil and waste motor oil, the development business adds to the roundabout economy, transforming disposed of materials into significant assets. As the development area endeavors to limit its ecological impression, the utilization of waste cooking oil and waste motor oil arises as a promising methodology for upgrading the maintainability of pavement development rehearses.

2.9 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR stands for Fourier Transform Infrared Spectroscopy. It is a procedure used to get an infrared range of ingestion or discharge of a strong, fluid, or gas. This strategy estimates the retention of various infrared frequencies by an example, giving data about the substance synthesis and sub-atomic construction of the example. FTIR is broadly utilized in different fields, including science, materials science, drugs, and ecological science, for subjective and quantitative examination of tests. It is known for its speed, minimal expense, and productivity in giving important data about the practical gatherings and synthetic bonds present in an example [10].

Subjective examination utilizing FTIR spectroscopy includes the recognizable proof of practical gatherings and sub-atomic designs present in an example in light of the trademark retention tops in the range. The remarkable phantom finger impression of the example gives data about its atomic structure, taking into account the separation and ID of various materials. FTIR spectroscopy is utilized for sub-atomic distinguishing proof, as no two different sub- atomic designs can deliver the equivalent spectra, making it helpful for subjective examination. This method has been applied for the recognizable proof, quality control, and assembling process management of drug drugs, showing its utility in subjective examination [11].

Table 2.1: Functional group of Asphalt Binder (C. D. DeDene, 2011)

Organic Compounds	Functional Groups	Wavelength (cm^{-1})
Saturated Hydrocarbons	C-H	2800-3100
Carbonyl	C=O	1750
Aromatics	C=C	1650
Aromatic Hydrocarbons	CH3, CH2 and C-H	1370-1535
Sulfoxide	S=O	1050
Butadiene	HC=CH	965
Alkanes	C-H	650-910

While investigating FTIR assimilation spectra quantitatively, standardized lists in light of pinnacle regions are processed to assess oxidation items. The carbonyl list ($I_{C=O}$) and the sulfoxide record ($I_{S=O}$) are utilized in previous exploration to survey useful gathering tops and depict black-top oxidation and aging [12]. To determine these records, to be specific the carbonyl file and sulfoxide list, one could utilize Eq-1 and Eq-2, which are given below.

$$I_{\mathrm{C=O}} = \frac{Carbonyl\ peak\ area\ (1700\ cm-1)}{Peak\ area\ (\sum 2000\ and\ 600\ cm-1)}$$

Equation 1: Structural Indices Equation for Carbonyl [13]

$$I_{\mathrm{S=O}} = \frac{Sulfoxide\ peak\ area\ (1030\ cm-1)}{Peak\ area\ (\sum 2000\ and\ 600\ cm-1)}$$

Equation 2: Structural Indices Equation for Sulfoxide [14]

2.10 Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM is a strong imaging instrument used to notice and investigate materials at a tiny scope, regularly going from micrometers to nanometers. SEM works by involving an engaged light emission electrons in a super high vacuum to produce high-goal pictures of the surface and inner design of an example. The critical standards and parts of SEM incorporate the usage of an engaged light emission electrons to interface with the example, giving nitty gritty data about its geology and synthesis. SEM gives imaging through the location of optional electrons (SEs) and backscatter electrons (BSEs), offering surface profile data and uncovering test piece, separately. Tests examined by SEM should be conductive or covered with a conductive material to diminish charging impacts and empower precise imaging. SEM instruments normally comprise of an example chamber or stage that obliges the example, an electron weapon that produces the electron bar, electromagnetic focal points for centering the shaft, and locators for catching the radiated electrons and creating pictures. SEM gives high-goal pictures of the inward designs of materials, taking into consideration the examination of mineral conveyance, void attributes, and even the generation of 3D pictures of the example's surface utilizing particular methods. Moreover, SEM can be outfitted with Energy-Dispersive X-beam Spectroscopy (EDS) identifiers to perform natural examination and recognize the essential creation of individual minerals in the example. In synopsis, SEM is a flexible device for microstructural examination, offering high-goal imaging and itemized portrayal of materials at the miniature and nanoscale. It is broadly utilized in different fields, including materials science, geography, science, and designing, to acquire bits of knowledge into the surface and inward construction of assorted materials

The current writing uncovers a significant collection of exploration on the presentation assessment of black-top covers changed with waste cooking oil and waste motor oil, especially zeroing in on present moment and long-term aging. Transient aging examinations regularly inspect the quick impacts of ecological openness on cover properties, while long-term aging investigations expand this examination over a lengthy period. Notwithstanding, there has all the earmarks of being an observable hole in the writing concerning expanded long-term aging examinations, where the cover modifier collaborations and execution are assessed under prolonged openness to natural circumstances. Expanded long-term aging, frequently reproducing certifiable situations, is pivotal for a comprehensive understanding of the cover's sturdiness, as it considers the impacts of aging past the traditional time spans.

One huge examination gap in the ongoing writing is the shortage of concentrates explicitly tending with the impacts of expanded long-term aging on black-top fasteners altered with waste cooking oil and waste motor oil. While present moment and long-term aging examinations give important bits of knowledge, a lengthy long-term point of view is vital for catch the total and supported effect of natural variables on cover execution. A top to bottom exploration of how these modifiers impact the folio's rheological properties, weakness opposition, and generally solidness over a lengthy assistance life is basic for creating vigorous and dependable asphalt materials.

One more noteworthy assessment hole lies in the changeability of aging conventions used in existing examinations. Standardization of aging techniques is fundamental to work with significant examinations between various exploration discoveries. While certain examinations utilize sped up aging strategies, others mimic normal aging circumstances. The absence of a reliable and broadly acknowledged aging convention prevents the capacity to draw decisive and generalizable bits of knowledge from the aggregate collection of exploration. Tending to this hole includes laying out standardized aging conventions that reflect certifiable circumstances and consider territorial varieties to upgrade the appropriateness of discoveries.

While existing examinations have surveyed the effect of waste cooking oil and waste motor oil on black-top folio properties, there is an exploration hole in terms of comprehensive execution assessment measurements. Expanded long-term aging investigations shouldn't just zero in on customary rheological properties yet additionally consider the effect on asphalt trouble systems, for example, rutting, breaking, and dampness powerlessness. A comprehensive assessment enveloping different execution pointer will give a more nuanced understanding of the viability and supportability of waste oil modifiers in black-top covers overstretched administration lives, filling a basic hole in the ongoing group of information.

2.11 Research Linked with Sustainable Development Goals

The exhibition assessment of various matured covers adjusted with squander cooking oil with regards to black-top asphalt development can be connected to a few SDGs.

- Cooperative efforts between specialists, industry, and policymakers to carry out and embrace feasible cover adjustment practices can add to accomplishing SDG 17(Partnerships for the Goals), underlining the significance of partnerships in accomplishing the more extensive reasonable advancement plan.
- The use of waste cooking oil as a modifier line up with SDG 12(Responsible Consumption and Production) by advancing responsible consumption and decreasing waste. It changes a byproduct into a significant asset for development.
- Black-top cover alteration with squander cooking oil might add to SDG13(climate action) by decreasing the dependence on conventional fossil-based fasteners, subsequently bringing down the carbon impression related with asphalt development.
- The maintainable utilization of waste cooking oil in black-top covers can by implication add to objectives connected with SDG14 (life below water) and SDG15(life on land) by lessening ecological contamination and advancing feasible practices in the development area.
- Cooperative efforts between specialists, industry, and policymakers to carry out and embrace feasible cover adjustment practices can add to accomplishing SDG 17(Partnerships for the Goals), underlining the significance of partnerships in accomplishing the more extensive reasonable advancement plan.

2.12 Chapter Summary

In conclusion, understanding the crucial role of asphalt binders in pavement construction underscores the necessity for ongoing efforts to enhance their performance. Waste cooking oil and waste engine oil, as potential modifiers, offer sustainable alternatives that not only address binder aging challenges but also bring about substantial environmental benefits. The adoption of these waste materials as modifiers aligns with broader goals of creating resilient, eco-friendly pavements. As research in this field progresses, the integration of waste cooking oil and waste engine oil may become integral components of pavement engineering, providing tangible solutions for both performance improvement and environmental sustainability in the construction of asphalt pavements.

CHAPTER 3: METHODOLOGY

3.1 General

The study's approach entails aging 60–70 grade bitumen for 5 hours, 8 hours, 11 hours, 14 hours and 17 hours using the Thin Film Oven Test (TFOT), and then modifying it with Waste Cooking Oil (WCO) and Waste Engine Oil (WEO) in percentages ranging from 1% to 5% by weight of the sample, as suggested by literature. Conventional tests are used to determine the ideal waste oil content at various aging times. These tests include penetration, softening point, ductility, flash point, and fire point. Further investigation is conducted using scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, and viscosity tests to examine the rheological, molecular, and microstructural alterations brought about by waste oil modification. The goal of this thorough method is to reveal the complex relationships that exist between binder qualities, age, and waste oil content. These findings will provide important information for the creation of robust and sustainable asphalt mixtures for use in road construction.

3.2 Selection of Materials

The objective of this study is to use waste oils to modify various aged binders into a state in which they have properties that are similar to those of virgin binders. Materials are chosen based on their cost-effectiveness and availability. The two categories of materials that are frequently employed in this research are as follows.

- Bitumen
- Waste oils

3.2.1 Bitumen

The bitumen chosen for this research is grade 60–70 bitumen, which is widely used for highway constructing throughout Pakistan. the asphalt merchant in Rawalpindi provided the bitumen, which was produced by National Refinery Karachi.

Typically, the term "virgin binder" is used in this research to refer to fresh, unaltered, or unaged bitumen.

3.2.2 Waste Oils

Waste cooking oil and waste engine oil are two of the many parts that make up waste oil, a complicated and heterogeneous mixture. This composition's uniqueness offers a chance to use sustainable methods to the building and upkeep of roads. In the realm of asphalt technology, reviving old binder is essential to improving the performance and longevity of asphalt mixtures. The writing has started to focus on the utilization of waste cooking and motor oil as rejuvenators. Researchers have investigated how these waste oils could possibly rejuvenate the mechanical and rheological qualities of old folio, which could prompt the making of affordable and earth gainful street framework arrangements. As well as resolving ecological issues related with their removal, the utilization of waste oils is in accordance with the bigger goals of asset effectiveness and the roundabout economy in the development business.

Figure 2.1: Waste Cooking Oil & Waste Engine Oil

3.3 Sample Preparation

The binder was first aged using the Thin Film Oven Test (TFOT) for different periods of time. Then, in accordance with suggestions from pertinent literature, waste cooking oil (WCO) and waste engine oil (WEO) were added in varying proportions (from 1% to 4% by sample weight). Employing a mixer, the precise and homogeneous mixing procedure was performed at a regulated temperature of 163 degrees Celsius. The rigorous sample preparation procedures set the stage for further testing and analysis, enabling a thorough assessment of the rheological, chemical, and microstructural characteristics of the modified binders.

Figure *3.2*: Addition of WCO & WEO to Samples

3.4 Tests on Samples

- Thin film oven Test
- Conventional Tests
- Rheological Tests
- Chemical Analysis
- Microscopical Analysis

3.4.1 Thin film oven Test

To simulate and evaluate the aging of bituminous materials, thin film oven tests are used. The results are useful for control of quality, choosing the material, research and development, & the design of pavements. It is essential for guaranteeing the lifetime & sturdiness of asphalt pavements in the transportation infrastructure.

3.4.1.1 **Apparatus**

- Thin Film Oven
- Aluminum Test Pans
- Thermometer

3.4.1.2 **Procedure**

- The sample was subjected to heat to make it flowable before being poured into the pans under the prescribed conditions.
- The thin film oven was preheated to a temperature of 163°C.
- The pans were carefully placed inside, noted the time, and left in the oven for 5, 8, 11 & 14 hours.
- Watch the oven temperature throughout time to guarantee a steady temperature.
- After selecting hours, take the sample from the oven, let it cool to room temperature, and then use it for additional testing.

Figure *3.4*: Thin film oven Test

3.4.2 Conventional Tests

For maintaining quality, assuring safety, & improving the performance of bituminous materials in a variety of construction applications, conventional Tests on bitumen are essential. They offer vital information that directs infrastructure design, building methods, and material choices. Below is a list of some of the conventional tests that were performed in this study.

- Penetration Test (ASTM D 5-05)
- Softening Point Test (ASTM D 36-95)
- Ductility Test (ASTM D 113-07)
- Flash & Fire Point Test (ASTM D 92-12A)

3.4.2.1 Penetration Test (ASTM D 5-05)

The main goal of this test is to evaluate bituminous material’s consistency, which is crucial in figuring out whether or not they are suitable for different applications. Consistency, which describes a material's degree of softness or hardness, is essential to how well bitumen performs under various circumstances.

3.4.2.1.1 Apparatus

- Penetrometer
- Steel Needle
- Water bath
- Metallic container

3.4.2.1.2 Procedure

- To remove the contaminants and make the sample flowable, it was first heated to a temperature of between 90 and 100 °C.
- Samples were placed in the container, filled to the prescribed range, and left at room temperature for around an hour.
- Following that, a container containing the sample was immersed in a water bath set at 25.5°C for approximately two hours.
- The sample was then put into the penetrometer, and the needle was adjusted such that it barely touched the surface.
- Allow the needle along with assembly to fully enter the sample for five seconds.
- One sample had at least 3 readings, and 3 samples were analyzed.
- Bitumen grade is the average of these three.

Figure *3.5*: Penetrometer and Samples

3.4.2.2 Softening Point Test (ASTM D 36-95)

The softening point test is used to assess the bitumen's thermal properties. It specifically seeks to ascertain the temperature at which bitumen changes from a solid to a more viscous or semi-solid condition, resulting in a change in its physical qualities.

3.4.2.2.1 Apparatus

- Ring & Ball Apparatus
- Glass Vessel & Thermometer
- Water Bath

3.4.2.2.2 Procedure

- A suitable bituminous material sample is produced before the softening point test is started.
- The ring and ball contraption is then set up, with everything in its proper position.
- The thermometer constantly records the temperature during this process while the testing ring filled with the sample is heated gradually and under control.
- Stirring is still essential for maintaining equal heating and preventing localized overheating.
- The steel ball softly penetrates the softened bitumen to a certain depth, which is the test's crucial phase and one that necessitates careful monitoring.
- The accepted softening point of bitumen is the temperature at which the ball touches the base.

Figure *3.7*: Ring & Ball Apparatus and samples

3.4.2.3 Ductility Test (ASTM D 113-07)

Bitumen's flexibility and elasticity are assessed by the ductility test to make sure it complies with construction standards. It helps with bituminous material selection, performance prediction, and quality assurance in general, especially in situations where flexibility is essential, such as highway construction and roofing.

In order to assess the bitumen's ductility, a sample is heated until it becomes soft. Then, a briquette specimen is formed from the softened bitumen. A testing machine secures the specimen, which is then pulled continuously at a consistent speed (50 mm/min) until it breaks or becomes discontinuous. The ductility value, which conveys crucial details on the flexibility & suitability of the bitumen, is the greatest distance it can stretch before failing.

3.4.2.3.1 Apparatus

- Ductility Apparatus
- Briquettes
- Spatula
- Glass Plate
- Water Bath

3.4.2.4 Flash & Fire Point Test (ASTM D 92-12A)

The crucial function of the flash & fire point test is to evaluate a material's flammability & combustibility (e.g., bitumen, petroleum products, or other volatile substances). In order to categorize and handle chemicals safely, create suitable storage and transportation systems, and reduce the danger of fires and explosions in industrial processes and everyday applications, this test is crucial for safety and regulatory compliance.

A sample is placed in a clean, dry test cup for the flash and fire point test. An ignition source, such as a gas flame or electric spark, is then periodically passed over the cup's aperture as the cup is heated at a regulated rate typically approximately 5°C/min. The fire point is the temperature at which the sample burns for at least five seconds after being ignited, whereas the flash point is the temperature at which a brief flash or flame is noticed.

3.4.2.3.1 Apparatus

- Cleave open cup
- Heater
- Thermometer

Figure 3.8: Flash and Fire Point Apparatus

3.4.3 Rheological Tests

- Viscosity Test (AASHTO T-316: ASTM D 4402)

3.4.3.1 Viscosity Test (AASHTO T-316: ASTM D 4402)

Rotating viscometers work on the fundamental tenet that the torque measured is related to dynamic viscosity. This torque is needed to move a spindle immersed in a fluid at a constant speed. The viscosity at high temperatures is measured in this test, which give a foundation for choosing the temperature for compaction and mixing.

The following tools are used to find samples' rotational viscosities.

- Rotational Viscometer
- Temperature Controller
- Spindle TR-9
- Sample Chambers
- Sample Chamber Rack
- Thermosdal

3.4.3.1.1 Procedure

- Pre heat the Thermosdal and sample temperature to a temperature at which test has to be done.
- Usually, the temperature is 135oC and 165oC.
- Heat the sample in oven at temperature 110° C such that it is sufficiently fluid.
- Pour the sample in sample chamber
- Place the sample chamber in thermosel and lower spindle in it
- Run the test for 30 minutes and read last three reading at interval of minute and take an average value.

Figure *3.9*: Rotational Viscometer

3.4.4 Chemical Analysis

- Fourier transform infra-red spectroscopy

3.4.4.1 Fourier transform infra-red spectroscopy

With Fourier Transform Infrared Spectroscopy, a molecular spectrum is determined by analyzing infrared radiation and plotting wave number on the x-axis and absorbance or percentage transmittance on the y-axis. This provides a crucial molecular fingerprint [11]. A FTIR spectrometer analyzes a sample to identify its functional groups and chemical bonds. The great sensitivity and specificity of this technique make it broadly applicable in a variety of domains, including chemistry, biology, materials science, and forensic research.

3.4.4.1.1 Apparatus

- FTIR
- Computer with all the necessary FTIR components

3.4.4.1.2 Procedure

- After solid materials are ground into powder, they are put in the FTIR.
- Infrared radiation is applied to the sample via FTIR.

- The radiation is absorbed by the sample and subsequently sent to the system.
- A computer then detects the radiation that was sent.
- The molecules will vibrate at different frequencies as a result of the infrared light absorbed by the binder sample; the covalent bond of a molecule will vibrate according to its inherent frequency.
- The natural frequency and spectrum of the functional group are distinct.
- After that, functional groups are found by comparing observed infrared radiation to a correlation table.

Figure 3.3: Fourier transform infrared spectroscopy Apparatus

3.4.5 Microscopical Analysis

- Scanning Electron Microscopy

3.4.5.1 Scanning Electron Microscopy

3.4.5.1.1 Apparatus

- Vacuum System
- Specimen Holder
- Electron Gun
- SEM Stubs
- Conductive Adhesive

- Coating Apparatus
- High Vacuum Chamber

3.4.5.1.2 Procedure

- Samples must be conductive and dry. To improve conductivity, non-conductive samples might need to be coated with a thin layer of metal (such as platinum or gold).
- The sample's dimensions and form must fit the SEM chamber.
- The prepared sample is placed into the SEM chamber, which needs to be vacuum-filled in order for the sample surface to interact with the electron beam.
- In order to generate a high vacuum environment that is required for the propagation of electron beams, the SEM chamber is emptied.
- A concentrated beam of electrons, usually accelerated at high voltages (such as 1–30 kV), is emitted by an electron cannon and directed at the sample.
- Interactions take place as the electron beam hits the sample surface. Emissions include backscattered electrons, secondary electrons, and distinctive X-rays.
- Diverse sensors pick up the signals that are released. While backscattered electron (BSE) detectors provide information on sample composition and crystal structure, secondary electron (SE) detectors provide precise surface topography.
- High-resolution images are produced by processing the signals that have been detected. While backscattered electron pictures emphasize compositional changes, secondary electron images highlight surface features.
- To achieve the best imaging conditions for particular aspects of interest, adjustments can be made to the beam intensity, focus, and other parameters.
- In order to comprehend the topography, morphology, and composition of the material, SEM images are studied. If the SEM has this feature, energy-dispersive X-ray spectroscopy (EDS) can be used to do elemental analysis.

3.5 Chapter Summary

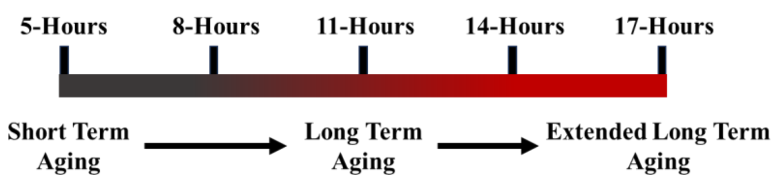
In summary, the study uses a methodical way to look at the connections between bitumen grades 60–70, aging, and the addition of waste cooking and waste engine oil (WCO and WEO). The first stage is to use the Thin Film Oven Test (TFOT) to age the bitumen for different amounts of time. Then, waste oils are added by writing proposals, which range from 1% to 4% by weight. To find the ideal waste oil content at different maturing times, customary tests like entrance, mellowing point, flexibility, streak point, and fire point are then utilized. After these tests, more assessment is completed with refined strategies such consistency testing, Fourier transform infrared (FTIR) spectroscopy, and scanning electron microscopy (SEM). The motivation behind this exhaustive examination is to explain the rheological, sub-atomic, and microstructural changes achieved by the treatment of waste oil. The far-reaching approach utilized expects to unravel the complicated connections between squander oil content, maturing cycles, and folio properties. The last goal is to give fundamental information to the making of sturdy and durable asphalt combinations that are fitting for use in development of streets. The acknowledgment in the part's decision is that these discoveries have a lot of potential to progress strong and naturally honest street framework standards.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 General

The likelihood of highway deterioration rises with billions of dollars' worth of freight traveling on such a network, underscoring the necessity of using a cost-effective strategy for highway restoration. It is necessary to use RAP as much as possible; nevertheless, research indicates that adding more than 20% of RAP to the mix will harden it, so rejuvenator must be added to the mix in order to soften the bitumen. The use of another waste, such as waste engine oil, holds the key to solving the issue. Because waste motor oil is wasted, it can be used as a rejuvenator and save money. Using waste engine oil also has a significant positive environmental impact.

The study uses the Thin Film Oven Test (TFOT) to age 60–70 grade bitumen for a duration of 5–17 hours. Waste Cooking Oil (WCO) and Waste Engine Oil (WEO) are added to the bitumen in 1%–5% ratios. To determine the optimum waste oil content at various aging times, conventional tests (penetration, softening point, ductility, flash point, and fire point) are carried out. Advanced methods such as Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), and viscosity tests are used in the inquiry to get insight into the rheological, molecular, and microstructural changes brought about by waste oil modification.



4.2 Penetration Test

The penetration test is carried out for five asphalt binders of varying ages at 25°C. A recurring pattern was observed: aged asphalts softened with increasing WEO or WCO dosages, regardless of whether WEO or WCO was administered. The penetration values of aged asphalts were significantly higher than those of VA, and with differing oil concentrations, different aged asphalts either reached or surpassed the hardness of VA.

As shown in the below figure-4.1, WCO's higher regeneration efficiency over WEO was confirmed by the fact that, despite having identical penetration effects, it was able to produce similar regeneration effects at lower concentrations. The recovery extents for asphalts aged 5 hours & 8 hours with 1% WCO is 101.52% & 94.85% respectively, for asphalts aged 11 hours and 14 hours with 2% WCO & 3% WCO is 103.03% & 102.02% respectively. Similarly for asphalt aged 17 hours with 4% WCO is 97.47%. On the other hand, with 1% WEO content, penetration recovery of up to 95.71%, was demonstrated by 5 hours aged asphalts as compared to VA. Similarly, with 2% WEO concentration, 8 hours aged asphalts showed recovery rates of up to 98.48%. Furthermore, with 3% WEO concentration, 11 hours & 14 hours aged asphalts showed a recovery rate of up to 102.02% & 96.16% respectively. Similarly for asphalt aged 17 hours with 4% WEO is 93.84%. This demonstrates how WEO can soften aged asphalt, with the effect of WEO content being more noticeable for particular types of aged asphalt. All the percentage recovery are showed in table 4.2. Also, the Penetration Grade for 5 hours & 8 hours are recovered from PG-(50-60) to PG-(60-70), and for 11 hours & 14 hours it recovered from PG-(40-50) to PG-(60-70). Whereas for 17 hours aging it recovered from PG-(30-40) to PG-(60-70). The Penetration Grade Recovery for all different aged binder i.e. 5 hours, 8 hours, 11 hours, 14 hours & 17 hours with optimum waste oils content are shown in table 4.3.

Furthermore, it may be concluded that WCO, which has lighter constituents, improved the flowability of aging asphalt. While increased WCO or WEO concentration produced better improvements, too much oil had a negative impact on other aged asphalt qualities. Depending on the degree of aging of the asphalt, an appropriate range of WEO or WCO concentration is essential. Reclaimed asphalt from actual reclaimed asphalt pavement (RAP) showed signs of deterioration that were more severe. Therefore, taking into consideration the unique aging conditions while selecting the ideal dosage of regenerative agent in road construction.

Table 3: Penetration Test Values of Different Aged Binder modified with WCO & WEO

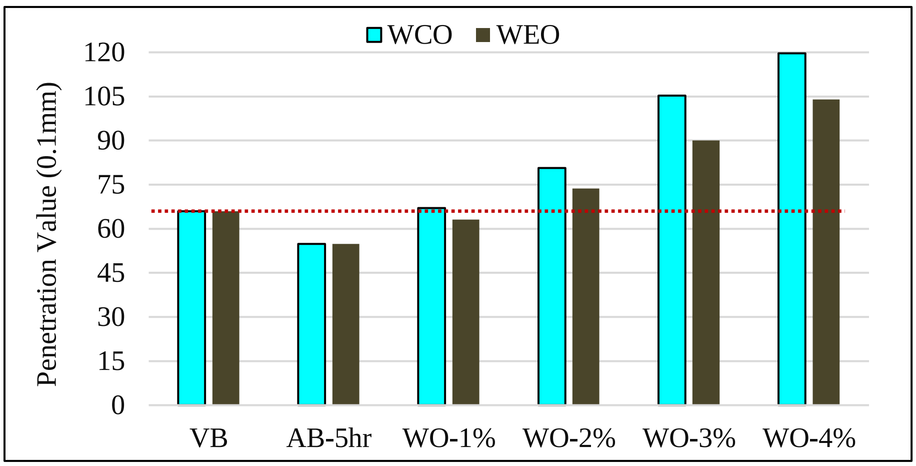
Penetration Values of Different Aged Binder						
	Waste Cooking Oil (%)					
Aging	Aged Binder	AB-C1	AB-C2	AB-C3	AB-C4	AB-C5
05-Hour	54.8	67.0	80.7	105.3	121.0	-
08-Hour	50.1	62.6	73.3	86	95.8	-
11-Hour	47	56.2	68	75.7	88.4	-
14-Hour	42.3	50.7	55.5	67.3	81.8	95.7
17-Hour	35.5	47.2	53.3	56.9	64.3	76.7
Aging	**Waste Engine Oil (%)**					
	Aged Binder	AB-E1	AB-E2	AB-E3	AB-E4	AB-E5
05-Hour	54.8	63.2	73.7	90.0	104.0	-
08-Hour	50.1	58	65.8	73.7	85.1	-
11-Hour	47	51.3	57.5	67.3	84.4	-
14-Hour	42.3	48.3	54.4	63.5	76.7	88.3
17-Hour	35.5	43	52	56.3	61.9	73.3

Table 4.1: Percentage recoveries of Different Aged Binder Penetration Values

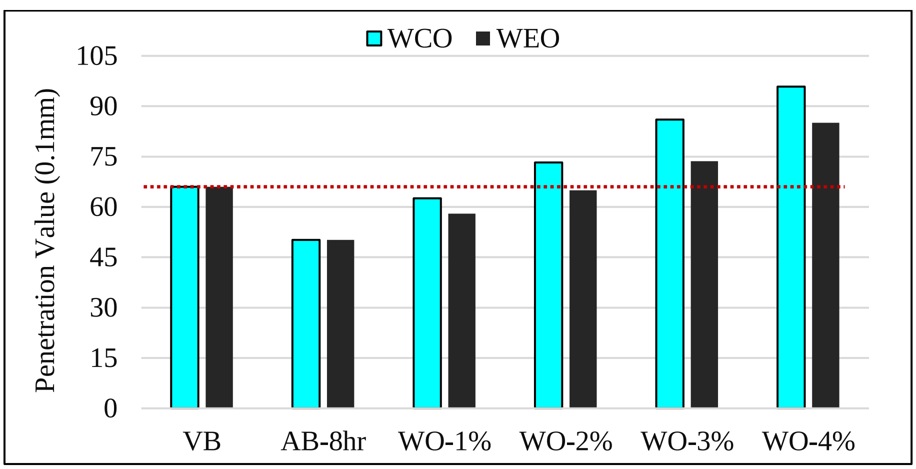
Penetration Values Percentage Recoveries						
Samples	Waste Cooking Oil			Waste Engine Oil		
Aging	%-Oil	P-Values	% Recovery	%-Oil	P-Values	% Recovery
05-Hour	1	67.0	101.52	1	63.2	95.71
08-Hour	1	62.6	94.85	2	65.8	98.48
11-Hour	2	68.0	103.03	3	67.3	102.02
14-Hour	3	67.3	102.02	3	63.5	96.16
17-Hour	4	64.3	97.47	4	61.9	93.48

Table 4.2: Penetration Grade Recovery

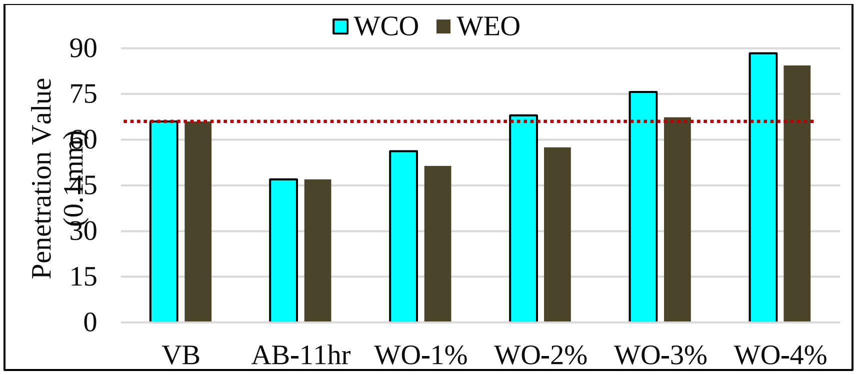
Penetration Grade Recovery				
Aging	**WCO (%)**	**WEO (%)**	**Penetration Grade**	
			From	**To**
05-Hour	1	1	50-60	60-70
08-Hour	1	2	50-60	
11-Hour	2	3	40-50	
14-Hour	3	3	40-50	
17-Hour	4	4	30-40	



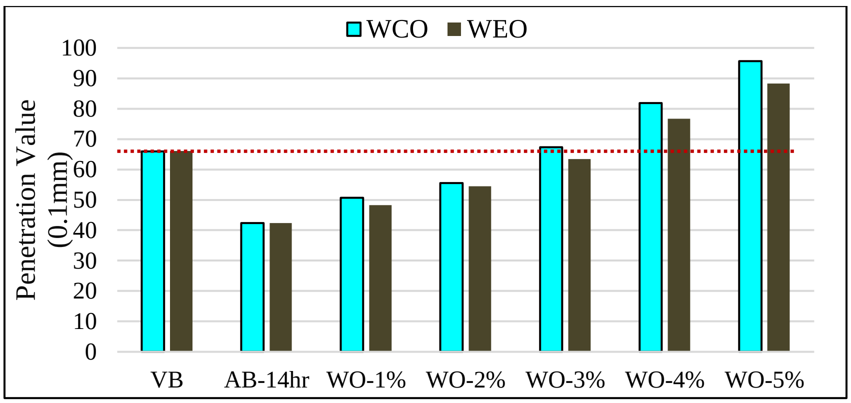
G-1: 5-hour Aged Asphalt Penetration Value



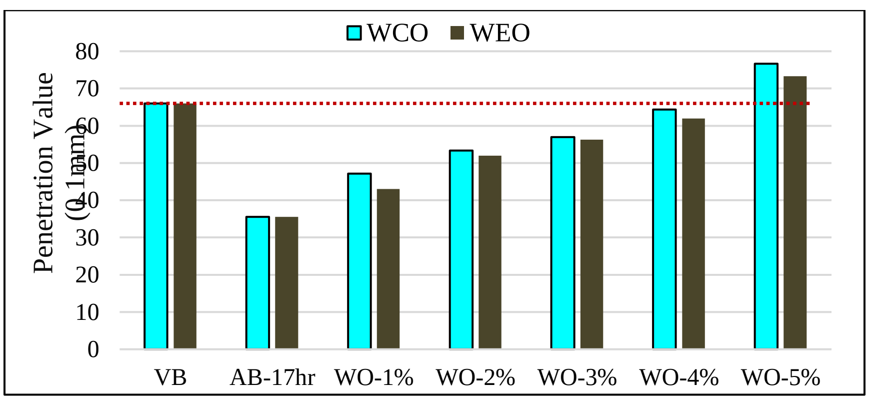
G-2: 8-hour Aged Asphalt Penetration Value



G-3: 11-hour Aged Asphalt Penetration Value



G-4: 14-hour Aged Asphalt Penetration Value



G-5: 17-hour Aged Asphalt Penetration Value

Figure 4.3: Penetration Test results of Different Aged Binder modified with WCO & WEO

4.3 Softening Point Test

Bitumen's softening point, which indicates its temperature susceptibility, is a key indicator of how well it performs in different applications. Higher penetration grades are indicative of bitumen that softens more readily at lower temperatures, which makes it appropriate for uses where flexibility is needed, such as constructing roads. On the other hand, bitumen with a greater softening point typically has a lower penetration grade, which indicates a stiffer composition. Because of this property, it can be used in situations where resistance to deterioration and durability are crucial, like roofing materials. To choose the right bitumen for a given engineering or developing project, one must comprehend the connection between penetration grade and softening point. The standardized test that uses two ring balls with a diameter of 9.5 mm offers a dependable way to figure out this crucial bitumen characterization characteristic.

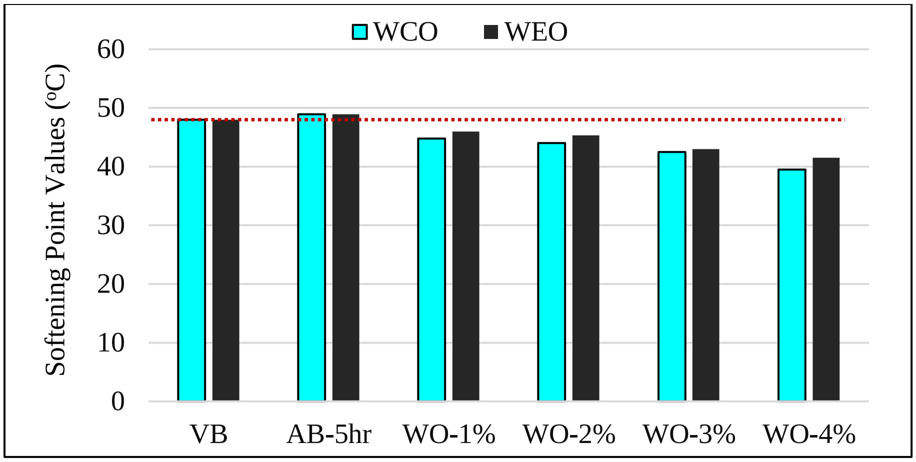
Figure 4.3 shows how WEO and WCO affect aged asphalts with varying aging durations in terms of their softening point. The softening point values of the aged asphalt binders were similarly seen to be decreasing with an increase in WEO or WCO contents, supporting the earlier conclusion in 4.1. As seen in Figure 4.2, various aged asphalts with varying oil contents may reach or surpass the VA softening point. In comparison, asphalts aged 5 hours, 8 hours, & 11 hours were able to recover up to 93.33%, 95.83%, & 97.92% respectively with 1% WCO, while asphalts aged 14 hours with 2% WCO and asphalts aged 17 hours with 3% WCO recovered up to 98.96% & 101.97% respectively in terms of softening point. In the meantime, the softening point was similarly impacted by the WEO. With 1% WEO content, the softening point of asphalts aged 5 hours & 8 hours recovered to 95.83% & 98.33%. While asphalts aged 11 hours with 2% WCO, asphalts aged 14 hours with 3% WCO & asphalts aged 17 hours with 4% WCO recovered to 101.67%, 98.33%, & 98.97% respectively. The percentage recoveries are shown in table 4.4 as below. This demonstrated that certain of the qualities of the aged asphalt could be restored by WEO, however the impact of WEO content on aged asphalt was more pronounced for particular aged asphalt types. An excessive amount of oil content might damage other aspects of aged asphalt, even though more WEO or WCO could lead to higher improved performance. The appropriate oil content was correlated with the asphalt's degree of age.

Table4.1: Softening Point Values of Different Aged Binder modified with WCO & WEO

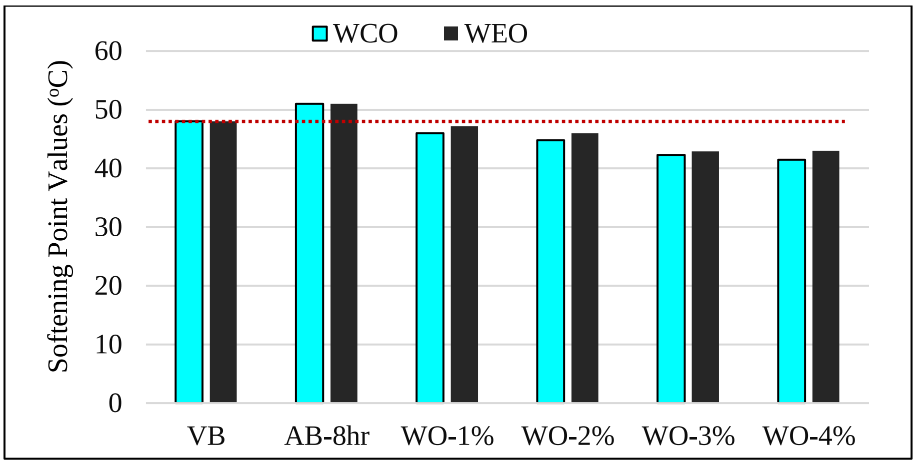
Softening Point Values of Different Aged Binder						
	Waste Cooking Oil (%)					
Aging	Aged Binder	AB-C1	AB-C2	AB-C3	AB-C4	AB-C5
05-Hour	48.9	44.8	44	42.5	39.5	-
08-Hour	51	46	44.8	42.3	41.5	-
11-Hour	53	47	45.8	44.6	43	-
14-Hour	54.6	50.4	47.5	45.8	44.2	43.4
17-Hour	55.4	52	49	48.8	46.5	45
	Waste Engine Oil (%)					
	Aged Binder	AB-E1	AB-E2	AB-E3	AB-E4	AB-E5
05-Hour	48.9	46	45.3	43	41.5	-
08-Hour	51	47.2	46	42.9	43	-
11-Hour	53	50.6	48.8	47.2	45.1	-
14-Hour	54.6	52	50	47.2	46	46
17-Hour	55.4	53.5	52.4	49.8	47.5	46

Table 4.2: Percentage recoveries of Different Aged Binder Softening Point Values

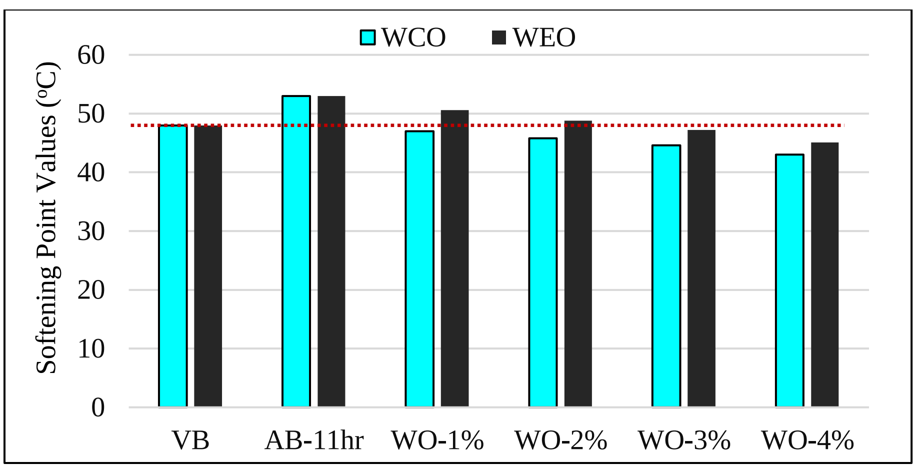
Softening Point Values Percentage Recoveries						
Samples	Waste Cooking Oil			Waste Engine Oil		
Aging	**%-Oil**	**SP-Values**	**% Recovery**	**%-Oil**	**SP-Values**	**% Recovery**
05-Hour	1	44.8	93.33	1	46.0	95.83
08-Hour	1	46.0	95.83	1	47.2	98.33
11-Hour	1	47.0	97.92	2	48.8	101.67
14-Hour	2	47.5	98.96	3	47.2	98.33
17-Hour	3	48.8	101.67	4	47.5	98.97



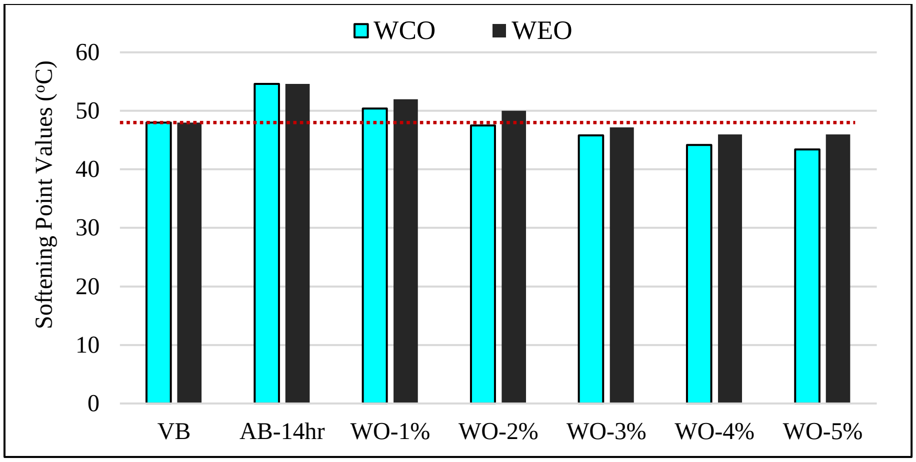
G-1: 5-hour Aged Asphalt Softening Point Value



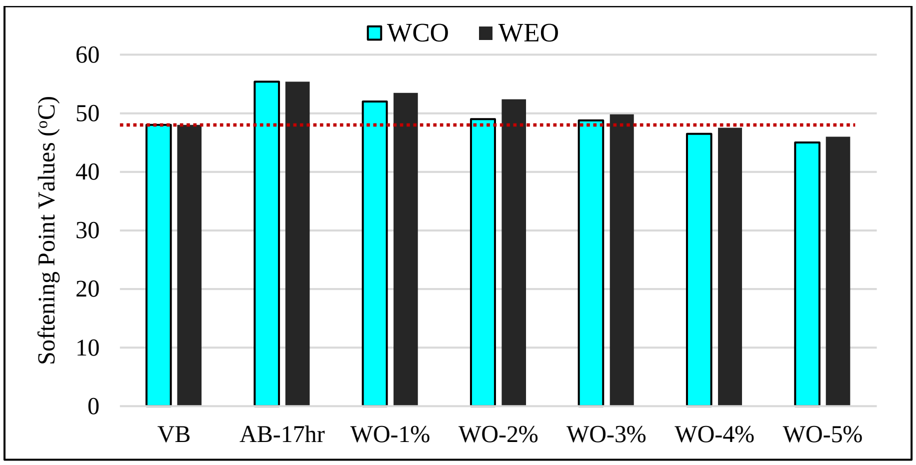
G-2: 8-hour Aged Asphalt Softening Point Value



G-3: 11-hour Aged Asphalt Softening Point Value



G-4: 14-hour Aged Asphalt Softening Point Value



G-5: 17-hour Aged Asphalt Softening Point Value

Figure4.1: Softening Point results of Different Aged Binder modified with WCO & WEO

4.4 Ductility Test

The ductility test is conducted on both virgin binder and several modified binders containing Waste Cooking Oil (WCO) and Waste Engine Oil (WEO) at a temperature of 25 degrees Celsius. The ductility result for the virgin binder was 131 cm, while all modified binders exhibited values above 100 cm. This suggests that all the modified binders meet the established criteria, as they surpass the 100 cm threshold. However, since the values of some modified binders exceeded the test range, for simplicity, we represent the modified binders collectively as a single bar with results exceeding 100 cm.

In summary, the ductility test outcomes indicate that the virgin binder has a ductility value of 131 cm, and all modified binders, despite some values exceeding the test range, consistently exhibit ductility values above the 100 cm criterion. As a result, we opt to represent the modified binders together as a single bar, emphasizing their conformity to the specified criteria of having ductility values exceeding 100 cm.

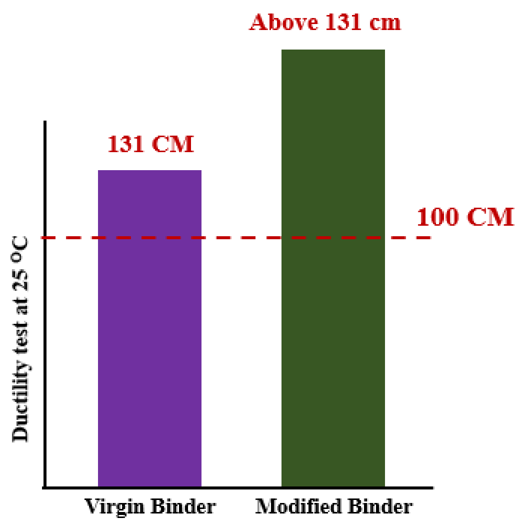


Figure*4.2*: Ductility of virgin asphalt and modified at 25°C

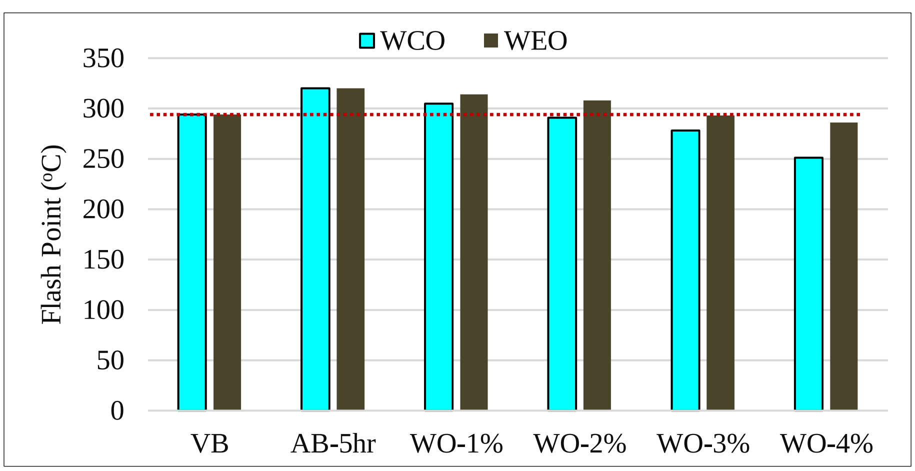
4.5 Flash and Fire Point Test

A fundamental strategy for deciding the combustibility properties of fluid materials, especially oil-based goods like bitumen, is the glimmer and fire point test. The most minimal temperature at which fluid fumes can quickly burst into flames when they come into contact with an open fire or flash is known as the blaze point. On the other hand, the temperature at which a fluid can consume constantly is known as the fire point. A higher blaze point is ideal for bitumen since it means expanded protection from touch off. This trademark is significant for handling, stockpiling, and transportation since it diminishes the gamble of openness to high temperatures or conceivable start sources. The discoveries of the glimmer and fire point tests, which are completed utilizing standardized hardware, are utilized to make wellbeing guidelines and assurance that bituminous material handling and transportation conform to legitimate necessities. Grasping these variables works with the administration of bitumen's fire wellbeing

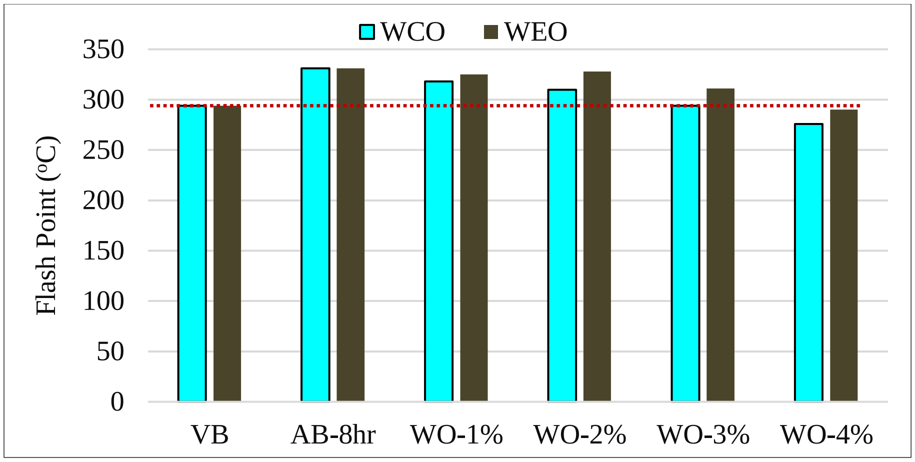
Components and ensures its protected application in various settings, like material and street development. The physical and synthetic properties of asphalt can modify because old enough, especially oxidative maturing. In spite of the fact that it's not unexpected information that blaze focuses are rising, it's memorable pivotal that there are various factors that can influence the amount of an increment there is. Openness to UV light, temperature changes, air quality, and the one-of-a-kind properties of the actual bitumen are a portion of the elements that influence how rapidly bitumen ages. An increase in the flash point temperature is typically indicative of the aging impact of asphalt. The lighter components in asphalt evaporate with age, leaving behind a higher proportion of heavier molecules, which usually raises the temperature of the flash point. Aging can also cause chemical processes like polymerization and oxidation, which raise the flash point and aid in the development of larger, less volatile molecules. As a result, compared to newly manufactured asphalt, aged asphalt typically has a greater flash point. The precise makeup of the asphalt, the length and conditions of age, and the existence of impurities or additives can all affect how much of an increase there is. By interacting with the asphaltene & maltene fractions, waste cooking oil (WCO) & waste engine oil (WEO) added to aged asphalt can change the flash point. WCO and WEO can lower the flash point since they include lighter, more volatile components, although the precise effect will vary depending on the unique properties of the oils and the old asphalt. These oils might interact with the molecules of asphaltene, thereby lowering their concentration and changing the asphalt's overall composition. Nevertheless, WCO and WEO have the potential to add more volatile substances, which lowers the flash point even further. The final impact on the flash point of the asphalt mixture is determined by the complex interplay of the dissolution of asphaltene, the addition of volatile substances, and the interaction with maltene fractions. Although every modified sample with an optimal binder content exhibits outcomes above the virgin binder, indicating that all are safe.

Table 5: Flash Point Test Values of Different Aged Binder modified with WCO & WEO

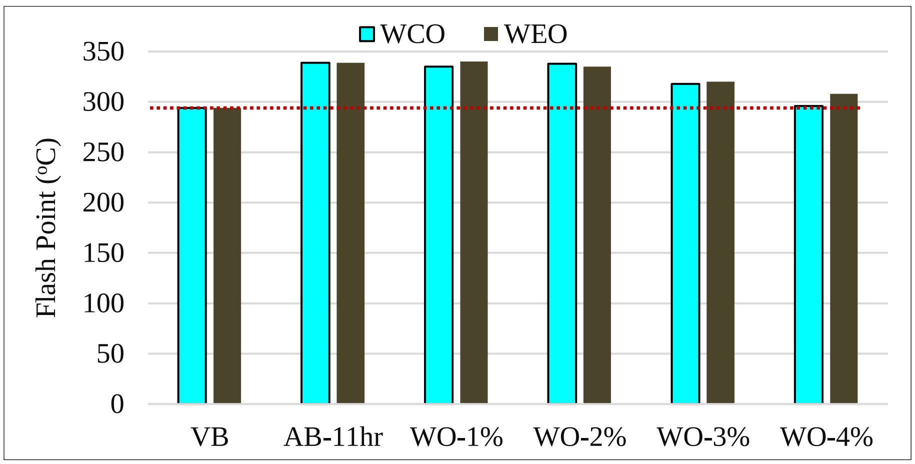
Flash Point Test Values of Different Aged Binder						
Aging	**Waste Cooking Oil (%)**					
	Aged Binder	AB-C1	AB-C2	AB-C3	AB-C4	AB-C5
05-Hour	320	305	291	278	251	-
08-Hour	331	318	310	294	276	-
11-Hour	339	335	338	318	296	-
14-Hour	357	342	330	329	305	289
17-Hour	375	359	347	343	324	310
Aging	**Waste Engine Oil (%)**					
	Aged Binder	AB-E1	AB-E2	AB-E3	AB-E4	AB-E5
05-Hour	320	314	308	293	286	-
08-Hour	331	325	328	311	290	-
11-Hour	339	340	335	320	308	-
14-Hour	357	339	345	329	319	301
17-Hour	375	351	360	350	343	332



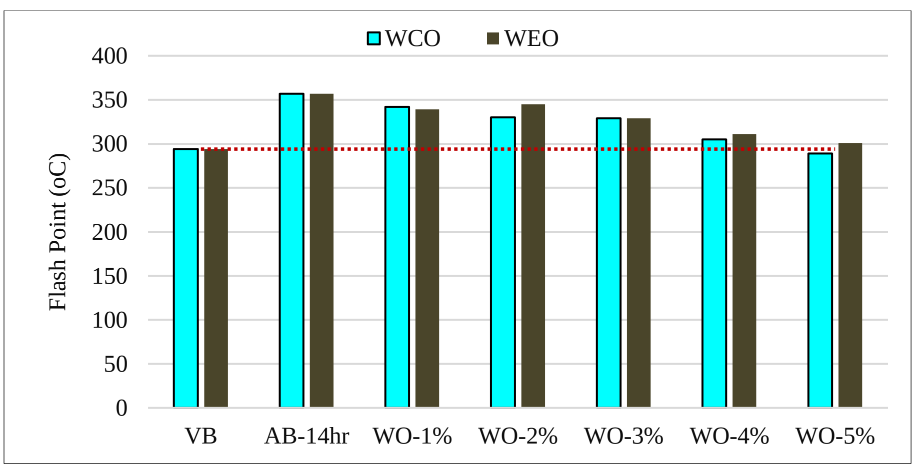
G-1: 5-hour Aged Asphalt Flash Point Value



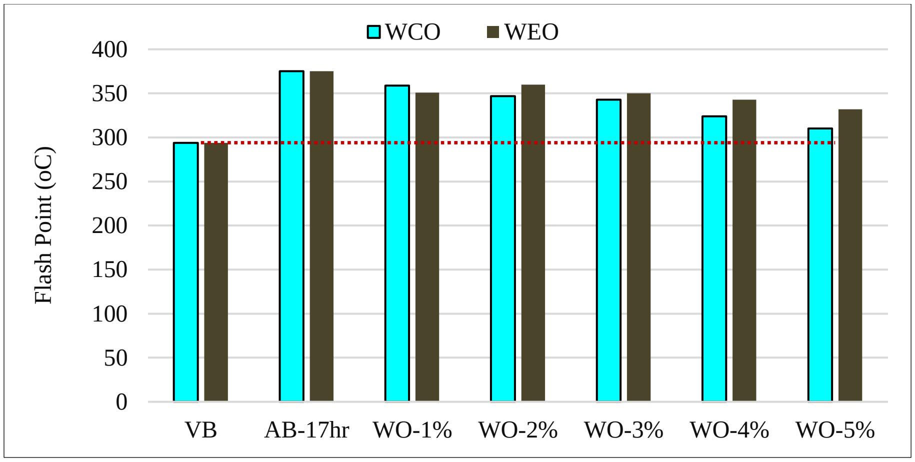
G-2: 8-hour Aged Asphalt Flash Point Value



G-3: 11-hour Aged Asphalt Flash Point Value



G-4: 14-hour Aged Asphalt Flash Point Value



G-5: 17-hour Aged Asphalt Flash Point Value

Figure *4.3:* Flash Point Test results of Different Aged Binder modified with WCO & WEO

4.6 Viscosity Test

Since rotational viscosity reflects the frictional resistance that interior molecules experience during deformation, it is an essential characteristic for comprehending the flow behavior of asphalt. At elevated temperatures, such as 135°C, the viscosity of asphalt is directly related to the mixing and compaction aspects of the asphalt mixture. This relationship emphasizes the significance of rotating viscosity as a gauge of the internal frictional forces in asphalt, offering insightful information on the material's flow properties in a variety of processing and environmental scenarios. Through the investigation of rotational viscosity at particular temperatures, like 135°C, scientists and engineers can get important insights to refine asphalt mixtures for improved durability and performance.

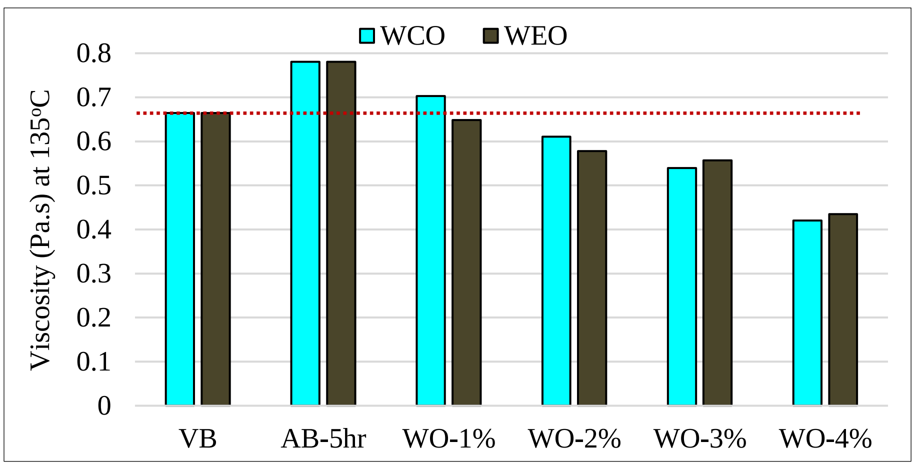
Figure 4.5 shows how WEO and WCO affect aged asphalts with varying aging durations in terms of their Viscosity Values. As seen in Figure 4.5, various aged asphalts with varying oil contents may reach or surpass the VA viscosity value. In comparison, asphalts aged 5 hours, 8 hours, & 11 hours with 1%, 3% & 4% WCO were able to recover up to 105.81%, 97.89%, & 95.73% respectively, while asphalts aged 14 hours & 17 hours with 5% WCO recovered up to 104.70% & 110.02% respectively. In the meantime, the Viscosity value was similarly impacted by the WEO. With 1%, 2% & 3% WEO content, the viscosity of asphalts aged 5 hours, 8 hours, & 11 hours were able to recover up to 97.65%, 102.48%, & 103.95% respectively. While asphalts aged 14 hours & 17 hours with 4% WEO recovered up to 102.44% & 96.47% respectively. All the values of rotational viscosity test of different aged asphalt binder modified with WCO & WEO are shown in table-4.5 and the percentage recovery values are shown in table-4.6. Excessive oil content would alter other aspects of aged asphalt, even though additional WCO or WEO could increase the frictional resistance of aged asphalt.

Table 6: R-Viscosity Test Values of Different Aged Binder modified with WCO & WEO

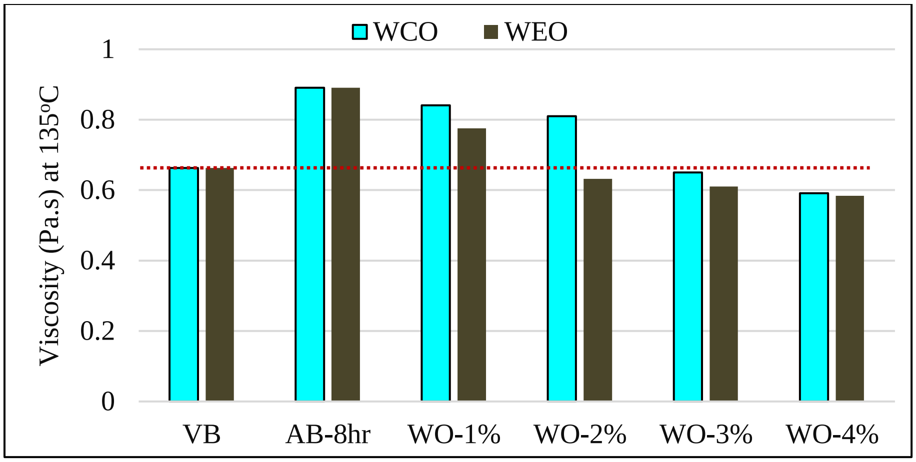
Viscosity Test (Pa.s) Values of Different Aged Binder						
Aging	**Waste Cooking Oil (%)**					
	Aged Binder	AB-C1	AB-C2	AB-C3	AB-C4	AB-C5
05-Hour	0.78	0.70	0.61	0.54	0.42	-
08-Hour	0.89	0.84	0.81	0.65	0.59	-
11-Hour	1.10	0.93	0.81	0.78	0.64	-
14-Hour	1.19	0.97	0.96	0.91	0.72	0.70
17-Hour	1.23	1.09	0.96	0.93	0.82	0.73
Aging	**Waste Engine Oil (%)**					
	Aged Binder	AB-E1	AB-E2	AB-E3	AB-E4	AB-E5
05-Hour	0.78	0.65	0.58	0.56	0.44	-
08-Hour	0.89	0.78	0.63	0.61	0.58	-
11-Hour	1.1	0.91	0.76	0.69	0.61	-
14-Hour	1.19	0.87	0.85	0.80	0.68	0.62
17-Hour	1.23	0.86	0.80	0.76	0.64	0.62

Table 7: Percentage recoveries of Different Aged Binder Rotational Viscosity Values

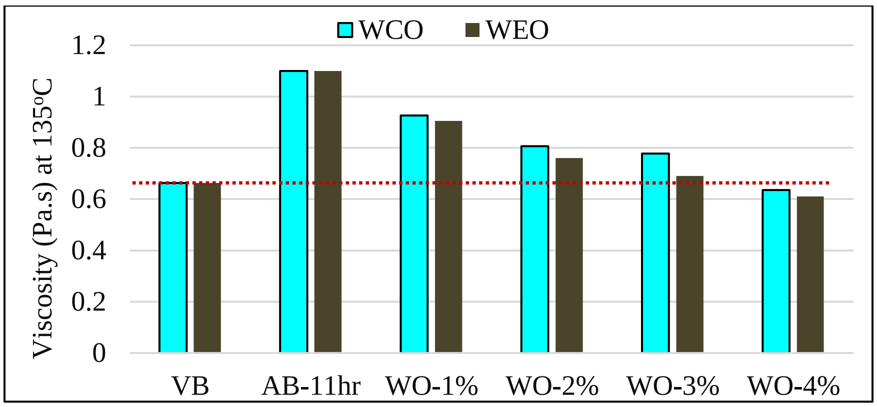
Viscosity Test (Pa.s) Percentage Recoveries						
Samples	Waste Cooking Oil			Waste Engine Oil		
Aging	**%-Oil**	**RV-Values**	**% Recovery**	**%-Oil**	**RV-Values**	**% Recovery**
05-Hour	1	0.70	105.81	1	0.65	97.65
08-Hour	3	0.65	97.89	2	0.63	95.19
11-Hour	4	0.64	95.73	3	0.69	103.95
14-Hour	5	0.70	104.7	4	0.68	102.44
17-Hour	5	0.73	110.02	4	0.64	96.47



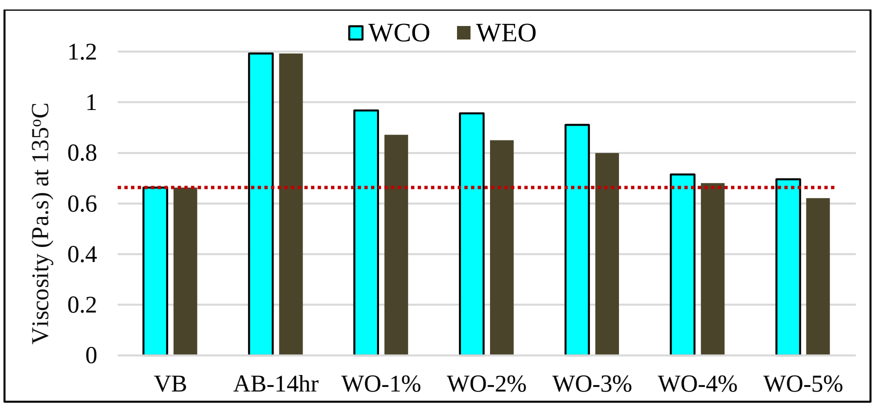
G-1: 5-hour Aged Asphalt Viscosity Value



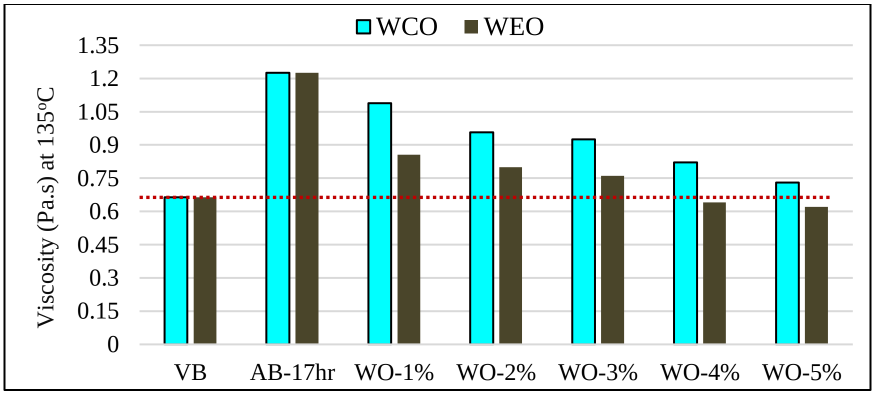
G-2: 8-hour Aged Asphalt Viscosity Value



G-3: 11-hour Aged Asphalt Viscosity Value



G-4: 14-hour Aged Asphalt Viscosity Value



G-5: 17-hour Aged Asphalt Viscosity Value

Figure*4.4:* RV Test results of Different Aged Binder modified with WO

The performance of the asphalt mixture could be negatively impacted by segregation if the recycled asphalt's viscosity increases to the point that the mixture is not evenly distributed. Asphalt roads are vulnerable to rutting if the recycled asphalt's viscosity drops too much. The WCO or WEO dose needs to be within a suitable range in order to meet the adhesion performance requirements of recycled asphalt. Following a comprehensive study that included penetration, softening point, ductility, flash point, and viscosity tests, the following tables outline the ideal composition for binders that are 5, 8, 11, 14, and 17 hours aged. Furthermore, the ductility values for the ideal contents that have been determined regularly above 100 cm, indicating compliance with the set parameters.

Furthermore, the findings of the flash point tests show that the results are within safe bounds, demonstrating the tested binders' suitability for the purposes for which they were designed. The combination of test findings offers important information on the properties and performance of binders that have undergone different age times, which aids in making well-informed decisions regarding asphalt and pavement engineering projects.

Table 8: Optimum content of WCO for different aged binder.

Optimum Content of Waste Cooking Oil (%)						
Aging Time (Hours)	< 5	5-8	8-11	11-14	14-17	> 17
Penetration Test	1	1	1-2	2-3	3-4	4
Softening Point Test	1	1	1	1-2	2-3	3
Viscosity Test	1	1-3	3-4	4-5	5	>5
Ductility Test	All the value are above 100 cm for the above optimums.					
Flash Point Test	For the above optimum content, all values are on the safe side.					

Table 9: Optimum content of WEO for different aged binder.

Optimum Content of Waste Engine Oil (%)						
Aging Time (Hours)	< 5	5-8	8-11	11-14	14-17	> 17
Penetration Test	1	1-2	2-3	3	3-4	>4
Softening Point Test	1	1	1-2	2-3	3-4	4
Viscosity Test	1	1-2	2-3	3-4	3-4	>4
Ductility Test	All are above 100 cm for above optimums					
Flash Point Test	For the above optimum content, all values are on the safe side.					

4.7 Fourier Transform Infrared (FTIR) Spectroscopy

The chemical composition of a sample can be analyzed using FTIR. It is a quick, affordable, and effective method for analyzing different substances both qualitatively and quantitatively. By comparing the sample's absorption bands to a reference library of known functional groups, qualitative analysis can determine which functional groups are present in the sample. In order to calculate the concentration of a functional group in a sample, quantitative analysis measures the strength of the absorption bands of particular functional groups in the sample and compares it to a calibration curve [15]. Three samples, virgin asphalt, modified asphalt, and aged asphalt were examined. The aged asphalt in the chosen samples is the extended long-term aged asphalt, and the modified asphalt is the same aged asphalt that has been altered with waste cooking oil.

4.7.1 Qualitative Analysis

FTIR tests have proved to be the most reliable method for chemical analysis of aged asphalt based on research conducted. To determine changes in asphalt chemical groups, FTIR was applied over a spectrum of 4000 cm−1 to 400 cm−1 which is the optimal range [16]. [17] From the figure, the different peaks for the asphalt binders in this study can be found, the polymeric bond found between 3200 cm−1 and 3700 cm−1 O-H stretching which appears as a broad & strong [18]. Another peak that is observed in the range of 2800 cm−1 and 3100 cm−1 is that of C- H stretching, which is the saturated hydrocarbons, i.e., alkanes, which appear as medium. As can be seen in Figure 7, that when artificial aging is applied, either no carbonyls or very little are generated. Therefore, there is a new peak at 1744 cm−1 in the modified binder, indicating the existence of a C=O bond, a type of aldehyde and ketone bond also known as a methanoyl or formyl group. This bond is responsible component for softening the binder, hence with increase in oil content such bond increases. The oxidation process that takes place in Asphalt and in the WCO sample throughout the frying process is what causes this type of bond to form [19]. The characteristic absorption peak at about 1626.88 cm−1 is that of C=C bond stretching, which is the aromatic hydrocarbons. The peaks at around 1458 cm−1 and 1376 cm−1 are linked to the deformation of aromatic hydrocarbons caused by the bending of CH2 and CH3 respectively [20]. The strong sulfoxide bond S=O is shown by the band at 1028 cm−1, and its relationship to the addition of oil is inverse. As stated otherwise, the values of sulfoxide bonds decreased with increasing oil content [21]. The fact that sulfur in asphalt binder is more reactive than carbon helps to explain its propensity [22] . Another peak that is observed in the range of 670 cm−1 and 913 cm−1 is that of C-H bond [20].

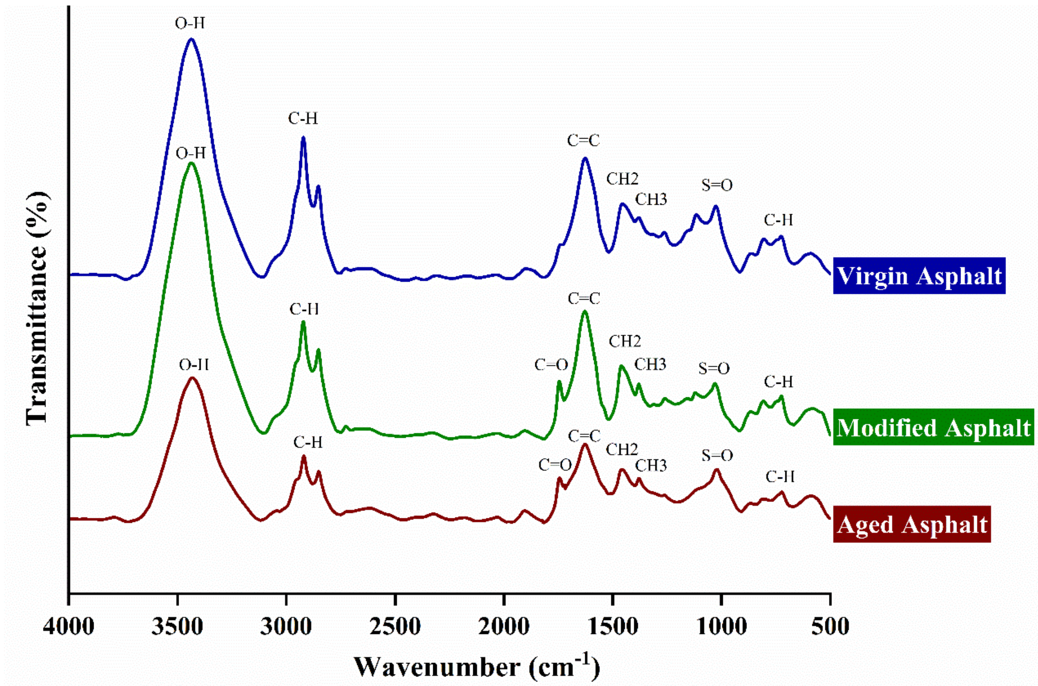


Figure*4.5* : FTIR Test results for Extended Long-term Aged Asphalt

4.7.2 Quantitative Analysis

When analyzing FTIR absorption spectra quantitatively, normalized indices based on peak areas are computed to evaluate oxidation products. The carbonyl index ($I_{C=O}$) and the sulfoxide index ($I_{S=O}$) are used in previous research to assess functional group peaks and describe asphalt oxidation and aging[23] . To determine these indices, namely the carbonyl index and sulfoxide index, one could use Eq-1 and Eq-2, which are given bellow.

$$I_{\mathrm{C=O}} = \frac{Carbonyl\ peak\ area\ (1700\ cm-1)}{Peak\ area\ (\sum 2000\ and\ 600\ cm-1)}$$

Equation 1: Structural Indices Equation for Carbonyl [13]

$$I_{\mathrm{S=O}} = \frac{Sulfoxide\ peak\ area\ (1030\ cm-1)}{Peak\ area\ (\sum 2000\ and\ 600\ cm-1)}$$

Equation 2: Structural Indices Equation for Sulfoxide [14]

The figure below displays the computed values for the sulfoxide & carbonyl indexes. An increase in the intensity of the carbonyl and sulfoxide bands in aged asphalt is correlated with a greater percentage of the most polar components, which make up higher molecular size (asphaltenes). The increase in carbonyl index and sulfoxide index values indicates that aging occurs solely due to artificial oxidation in Lab. As a result, bitumen aging may result in a rise in asphaltene content, which raises the asphaltene to maltene ratio and significantly affects the physical characteristics of asphalt [2]. Similarly, due to the fact that sulfur reacts more than carbon, as was previously discussed that's why sulfoxide index value increases more than that of carbonyl. Hence, adding WCO as a rejuvenating agent causes the asphaltene content to decrease while the maltenes grow and reach the desired ratio. Figure illustrates this well, showing how adding WCO can raise the carbonyl index and decrease the sulfoxide index. Thus, it implies that bitumen's chemical composition can be restored, the amount of asphaltene can be decreased, and the maltenes can be increased by using WCO as a rejuvenating agent.

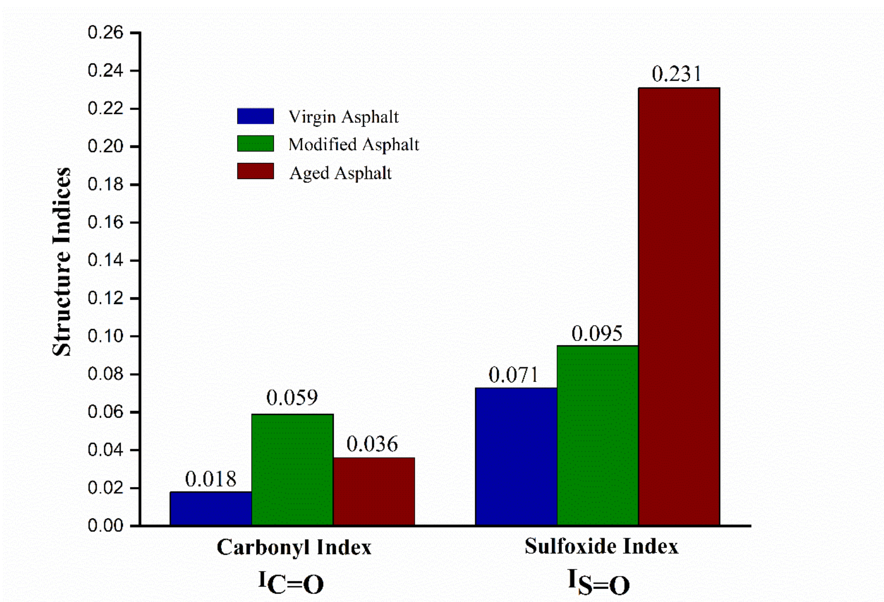
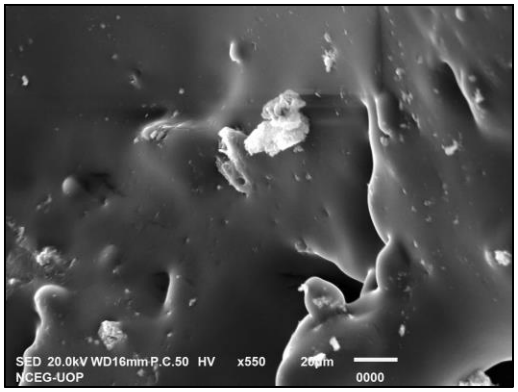


Figure *4.6:* Comparison of Structure indices

4.8 Scanning Electron Microscopy

Through SEM images, Figure below offers a detailed view into the properties of both aged and modified asphalt. Following 17 hours of aging, the SEM picture presented in Figure 4.7 A and 4.7 B, reveals minute but noticeable alterations in the structure of the asphalt, which appear as tiny creases and flaws strewn throughout some surfaces. These findings clearly show that the aging process has had a noticeable impact on the overall integrity of the asphalt. Interestingly, when WCO is added to aged asphalt, it doesn't really vary in look from the pre-modified asphalt as shown in figure 4.8 A and figure 4.8B. But when you look closer, you can see sporadic microscopic white specks that are probably leftovers of WCO particles that were added during the lab test preparation stage. This behavior suggests that the renewing agent and the asphalt matrix interact in a complex way. The potential benefits of these compounds in asphalt rejuvenation procedures are further supported by the expectation of a similar impact when using WEO.

On the other hand, figure below offers an impressive account of revitalized asphalt, exhibiting significant improvements in its characteristics even though it appears to be less uniform. An important conclusion is highlighted by this disparity between homogeneity and performance improvement: WEO or WCO are effective regeneration agents after concentration filtering. Previous testing has demonstrated significant improvements in the rejuvenated asphalt's qualities, supporting the idea that these waste-derived materials could be useful in enhancing asphalt performance. Crucially, the existence of any lingering minuscule particles seems to have very little effect on the overall effectiveness of these agents, indicating that the potential advantages of these agents much exceed any slight drawbacks. Therefore, these images from SEM highlight the feasibility of using waste-derived materials to improve asphalt performance in addition to providing insightful information on the morphological changes brought about by aging and rejuvenation processes.



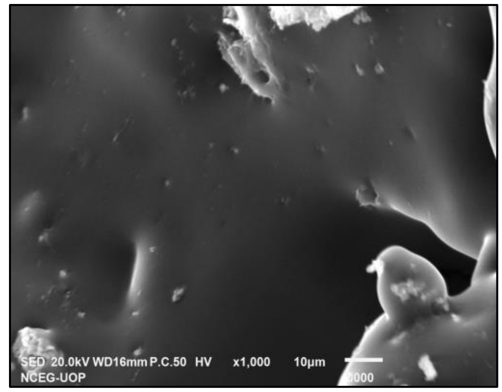
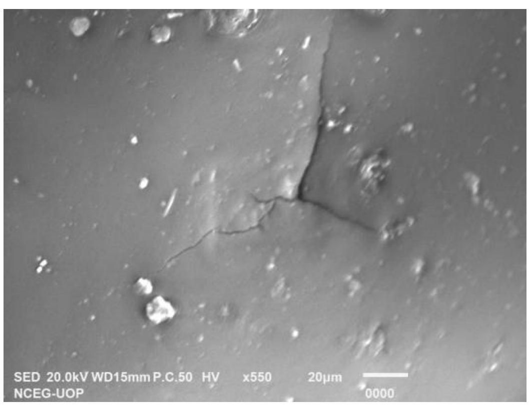


Figure 4.7-A: Aged Asphalt = x550 Times **Figure 4.7-B:** Aged Asphalt = x1,000 Times



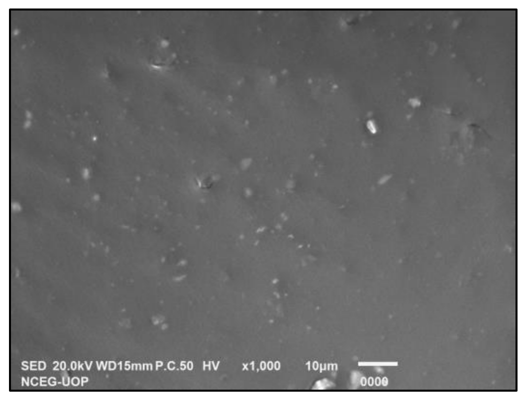


Figure 4.8-A: Modified Asphalt = x550 Times **Figure 4.8-B:** Modified Asphalt = x1,000 times

4.9. Chapter summary

By testing the penetration, softening point, ductility, flash point, viscosity, and chemical composition of asphalt binders of different ages, the study evaluated the effects of waste cooking oil (WCO) and waste engine oil (WEO). Aged asphalts were satisfactorily softened by both oils; however, WCO demonstrated higher regeneration efficacy, recovering up to 110% of the viscosity and up to 103% of the penetration for different aged samples. WEO showed marginally reduced recovery rates despite its effectiveness. All of the modified binders met PERFORMANCE standards since their ductility values were more than 100 cm. According to research on flash points, the lighter components of both oils could lower the flash point. Significant improvements in viscosity were observed, with ideal oil concentrations regaining flow characteristics; nevertheless, an excess of oil may have adverse effects on performance.WCO improved chemical composition by increasing maltenes and decreasing asphaltene levels, according to FTIR analysis. SEM pictures verified that although the oils enhanced the properties of the asphalt, the advantages were contingent on the amount of oil and the age of the asphalt. In general, WCO and WEO work well for rejuvenating asphalt if their application is well managed.

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

5.1. Summary

Waste Engine Oil and Waste Cooking Oil has shown that they are capable of bringing aged asphalts' basic physical properties back to normal. The dosage of either Waste Engine Oil and Waste Cooking Oil must be carefully considered in order to achieve best performance in regenerated asphalt, as it varies based on the unique properties of the aged asphalt that needs to be treated. WCO performs better than WEO when compared as regeneration agents. Within certain dosage ranges, aged asphalt can restore its basic physical qualities with the addition of WCO: up to 1% for short-term aging, 4-5% for long-term aging, and up to 6% for extended long-term aging. This is dependent on the length of the aging process. However, multiple dose levels are needed for rejuvenating aged asphalt with WEO: up to 1% for short-term aging, 3-4% for long-term aging, and more than 4% for protracted long-term aging. These dosage criteria, which are stated as a percentage of the mass of the asphalt, make sure that the rejuvenation process successfully recovers the asphalt's performance characteristics. They also highlight the specific dosing needs that must be met for the best results depending on how long the asphalt has aged.

5.2. Conclusions

In conclusion, the qualitative analysis of FTIR results has provided valuable insights into the interaction between waste cooking oil (WCO) and aged asphalt binder. The absence of additional chemical compounds suggests a physical blending of WCO with the aged binder rather than a chemical reaction. This qualitative observation aligns with the idea that WCO serves as a rejuvenating agent by physically enhancing the binder's properties, thus offering a sustainable approach to mitigate asphalt aging.

The quantitative analysis of FTIR results unveils a crucial correlation between the intensity of carbonyl and sulfoxide bands in aged asphalt and the percentage of polar components, particularly higher molecular-sized asphaltene. The increase in carbonyl and sulfoxide index values points towards aging primarily induced by artificial oxidation in the laboratory setting. This artificial aging process leads to a rise in asphaltene content, altering the asphaltene to maltene ratio and consequently influencing the physical characteristics of the asphalt. The observed increase in sulfoxide index, attributed to sulfur's higher reactivity than carbon, underscores the significance of oxidative aging in asphalt binders.

The introduction of waste cooking oil as a rejuvenating agent demonstrates promising outcomes in mitigating the effects of aging. The decrease in asphaltene content and the simultaneous growth of maltenes, as indicated by the carbonyl and sulfoxide indexes, suggest that WCO plays a crucial role in restoring bitumen's chemical composition. The physical properties of asphalt, affected by asphaltene to maltene ratio changes, are therefore positively influenced by the addition of WCO. This implies a potential avenue for sustainable asphalt modification, where WCO acts not only as a physical enhancer but also as a rejuvenating agent, contributing to the overall resilience and durability of asphalt binders.

5.3. Recommendations:

Based on your conclusion, here are some recommendations for future research:

Future studies should assess binder performance under a variety of environmental circumstances, such as severe temperatures and humidity, and expand aging models beyond the current 17-hour timeframe to include several months or years of exposure. To give a thorough evaluation of long-term durability, it should also include performance testing for rutting resistance, fatigue cracking, and moisture sensitivity. Furthermore, investigating substitute waste materials and performing field research on modified binders will provide useful understandings of their performance in actual use. The benefits and trade-offs of employing waste oils in asphalt will be further clarified by advanced chemical and microstructural analyses in conjunction with economic and environmental assessments. This will result in binder compositions that are more sustainable and efficient.

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