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Synergetic Effects of Waste Engine Oil and Crumb Tyre Rubber on Bitumen Modification

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ABSTRACT

Bitumen is a widely used road infrastructure material exhibiting black color and sticky consistency and is known for its versatile use and thermoplastic nature. In recent years, predicting road life has been arduous due to increasing traffic, global warming, and ever-changing stresses on pavements. Meanwhile, a large amount of waste engine oil (WEO) and vehicle tyres from various automobiles is disposed of into the atmosphere as hazardous waste. Relatedly, heavy metals and the huge capital involved in the sustainable treatment of these materials have been challenging. Therefore, this study aims to analyze modified bitumen using (WEO) in combination with waste crumb tyre rubber (CTR), thus reducing virgin bitumen (VB) use and making bitumen a sustainable material. During the characterization of modified bitumen, the following WEO concentrations were utilized: 3%, 5%, 7%, and 9%, and the following CTR concentrations: 5%, 7%, 9%, 12%, and 15%. The properties of modified and virgin bitumen were compared. It has been found that the blend of 5% CTR and 9% WEO exhibit the highest penetration value and the lowest softening temperature of all the samples examined. As a result, this mixture can be used to reduce the excessive brittleness of bitumen to a greater extent. Moreover, the flash and fire point values have increased after modification, while the ductility and specific gravity values have decreased. In summary, the modified bitumen has shown promising results regarding physical changes in bitumen.

Keywords: Modified bitumen; crumb tyre rubber; waste engine oil; physical properties; sustainability

INTRODUCTION

The pivotal role of roads in propelling economic growth and promoting social mobility is undeniable. Roads serve as connectors between communities, granting access to essential services like healthcare, education, and employment that are paramount for fostering progress and development. In fact, the increase in vehicles on the road is often seen as a symbol of economic development (Liu 2008). Hence, expanding road infrastructure has been a key focus of policymakers and planners since the 1900s (Forman 2003), with significant investments made toward improving connectivity and access. However, this drive towards greater mobility has brought with it several challenges. Firstly, the construction of longer road spans and increased traffic pressure has resulted in a surge in material consumption, putting pressure on limited resources. Secondly, the rise in vehicular traffic has led to greater wear and tear on existing roads (Gardezi 2018), necessitating frequent maintenance and repair. Thirdly, the increased number of vehicles has resulted in the disposal of millions of tyres each year, contributing to environmental pollution and waste management challenges. Finally, the surge in vehicle use has led to the disposal of significant amounts of waste engine oil, posing a threat to the environment and public health (Nerın 2000).

To address these multidimensional challenges, waste engine oil (WEO) and waste tyres in the form of crumb tyre rubber (CTR) have been incorporated into the bitumen modification in this study. Bitumen is one of the earliest engineering materials (Masliyah 1995). It has been used as an adhesive, sealer, preservative, waterproofing agent, and pavement binder for thousands of years (Polacco 2006). Bitumen's chemical composition, particularly the molecular structure, affects its physical, rheological, aging, and adhesion-related characteristics (Hunter 2015).

Therefore, excellent bitumen qualities may be produced by choosing good crude oil or appropriate refining procedures. However, the absence of effective control measures during the refinery, limited oil resources for manufacturing high-quality bitumen, and the need to maximize economic advantages have led industries to pay greater attention to bitumen modification (Yildirim 2007). As a result, bitumen modification has gained popularity in the research world. It is true that commercially available modifiers, such as fillers, extenders, polymers, fibers, antioxidants, etc., are often added to bitumen to improve its performance; however, with their use, the cost-benefit ratio of these mixtures declines (Khurshid, 2021). To address this gap, this research incorporates WEO and CTR for bitumen modification considering their adverse impact on the environment and the financial costs of recycling.

Modifying bitumen's physical and mechanical properties in road construction applications using crumb tire rubber (CTR) is a widely adopted technique that depends on the complex interplay of physical and chemical interactions, which are controlled by the surface chemistry of rubber particles and their affinity for bitumen. The composition of the rubber particles, including carbon black and other additives (Sienkiewicz 2017), enables uniform dispersion throughout the bitumen matrix and interacts with both polar and non-polar components of the bitumen (Rahimi 2006). This interaction improves adhesion through cross-linking and entanglement of the rubber particles with the bitumen matrix (Wang, 2020). As a result, the underlying physical chemistry of the modification mechanism facilitates improved adhesion, cross-linking, and entanglement between the two components, ultimately culminating in the improved physical and mechanical characteristics of the modified bitumen.

From a fractional point of view, bitumen is composed of a matrix of maltenes and asphaltenes. Asphaltenes impart hardness to bitumen, while maltenes contribute to its consistency. Adding CTR to bitumen raises the concentration of asphaltenes fraction, leading to the formation of stiffer bitumen. Nevertheless, the variability in the physical and chemical properties of CRMB due to the complex composition of bitumen and the presence of polar heteroatoms should be considered, as it affects the rheology and consistency of the modified bitumen. The rheology and consistency of bitumen can be improved by incorporating waste engine oil (WEO) as a modifier for crumb rubber-modified bitumen. The lightweight maltenes in WEO provide viscoelastic properties to bitumen, while WEO is a carrier of these maltenes (Nandakumar 2021).

Additionally, using WEO in bitumen modification decreases the amount of virgin bitumen required (Wulandari 2017), thus reducing energy consumption and associated greenhouse gas emissions. WEO has a high calorific value, which increases the energy content of the bitumen mixture, potentially reducing the required heating time and leading to energy and time savings, contributing to the economic viability of operations. Ergo, utilizing waste engine oil (WEO) and crumb tire rubber (CTR) for bitumen modification is an economical, eco-friendly, and energy-efficient approach.

LITERATURE SURVEY

The history of bitumen modification is both lengthy and varied, with examples ranging from the use of natural bitumen to the incorporation of rubber (Attanasi 2007). Especially extensive research has been carried out on a wide range of polymer-modified bitumen (PMBs) to explore their rheology, mechanical properties, thermal behavior, morphology, storage stability, aging, and temperature sensitivity (Wardlaw 1992). This is because the physical and mechanical properties of bituminous binders tend to deteriorate over time, affecting their viscosity, softening point, loss modulus, and storage modulus (Ali 2013). Considering this, these parameters have emerged as the primary area of interest in current studies on modified bitumen. Moreover, besides the PMBs, other modifiers such as oils, coal tar, and tyre rubber have also been utilized to produce quality bitumen (Mamvura 2020).

Crumb rubber has been found to substantially alter the physical characteristics of bitumen, including viscosity, penetration, and softening point (Read 2003). The primary reason behind such changes is the polymerization of bitumen, which enhances its properties, such as improved stiffness at high temperatures, increased resistance to cracking at relatively low temperatures, improved resistance to moisture, and improved fatigue life (Alataş 2013). During the incorporation of crumb rubber in bitumen, the rubber particles expand upon coming into contact with the bitumen, altering the physical properties of the modified bitumen (Peralta, 2010). Hence, this modification is not limited to physical properties; the modulus of resilience, rutting resistance, and fatigue cracking resistance of bitumen are also enhanced when rubber crumbs are added to asphalt mixtures (Thomas, 1995).

However, thermal instability and phase separation problems have been observed in certain polymer-modified bitumens (PMBs), leading to limitations in their use (Thomas 1995). Additionally, it is crucial to address the size of the crumb rubber tyre when handling CR-modified bitumen. This parameter plays a significant role in the CRMB's performance as the finer particle size results in the bitumen having greater softening temperatures, viscosity, and elasticity, as it has a larger surface area (Putman 2006). Whereas research indicates that using coarse particles and high rubber content requires higher mixing temperatures to produce modified bitumen resistant to rubber segregation and settling (Attia 2009). Besides, extreme caution is necessary while mixing at high temperatures as the rubber depolymerizes and distributes throughout the mixture for an extended period, degrading the binder's properties (Chehovits, 1989). This depolymerization of rubber is influenced by several factors, such as mixing rate, mesh size, and temperature (Leite, 2001) (Lee, 2008). Moreover, the properties of the bitumen used to produce crumb-modified bitumen (CRMB) substantially impact the product's final quality (Ibrahim 2013).

Incorporating polymers into bitumen has been shown to enhance several important properties of the bitumen, such as its resistance to rutting at high temperatures and cracking at low temperatures (Valkering 1990). Also, Using CRMB in asphalt pavements also promotes resource conservation and sustainability in the pavement industry, as it reduces the required amount of bitumen, as demonstrated by (Wulandari 2017). However, a lower bitumen content in the mixture can increase permeability, improving drainage properties and reducing durability due to air voids in the pavements. Despite the popularity of CRMBs, challenges such as thermal instability and phase separation persist. Hence, this study incorporates waste engine oil (WEO) along with crumb rubber for bitumen modification, which further improves the low-temperature cracking resistance in crumb rubber-modified binders (CRMBs) (Fernandes 2018).

The production rates of waste engine oil (WEO) in the auto engine oil (E.O.) industry are notoriously high, generating 40 million tons annually (Opoku-Mensah 2023). Due to frequent usage, E.O. often becomes contaminated with metallic debris, causing its usable life to vary with time and intensity (U.S. Environmental Protection Agency, 2023). Unfortunately, WEO contains hazardous elements that threaten the environment and human health (Pinheiro, 2017), necessitating frequent draining and replacement. Although refining, cogeneration, and combustion utilize WEO, they are typically expensive, resource-intensive, and generate harmful residues (Yilbaşi 2023). Given these concerns, incorporating WEO in bitumen modification remains attractive (Yang 2020).

Maltenes, as a lightweight fraction, provide bitumen with viscoelastic properties at room temperature (10-40°C), while oils, which are carriers for maltenes, are commonly used for bitumen modification (Nandakumar 2021). In several studies, the addition of waste engine oil (WEO) to aging asphalt pavements has been shown to improve the bitumen's viscosity and softening point (Shi, 2023). Furthermore, it has been found that bitumen's viscosity and temperature sensitivity increase with an increase in aromatic compounds (Jeong 2010). Moreover, WEO also has potential as a regenerant, as demonstrated by the effectiveness of recycled asphalt components containing it (DeDene 2014). A thorough scrutiny of the literature underscores the challenges related to the use of unmodified bitumen, thereby providing a rationale for the incorporation of WEO and CTR to enhance the bitumen's properties and optimize the operational efficiency.

METHODOLOGY

STUDY MATERIALS

This study uses 80/100-grade bitumen, waste engine oil without pre-treatment, and crumb tire rubber of size #30 mesh. The bitumen industry has experienced a substantial boost in both its trade volume and financial value. According to the global bitumen market research report (Fortune Business Insights, 2021), the bitumen industry is anticipated to expand by 3.8%, and the global market value will increase from USD 51.69 billion in 2028 to USD 67.14 billion. Another report reveals that the global bitumen market, in terms of volume, was estimated to be 118.5 million tons in 2020 (Global Market Insights, 2021). In addition, WEO production and disposal constitute a significant environmental hazard, with millions of tons generated annually. Approximately 40 million metric tons of engine oil are required globally, roughly 50% used for transportation. Only about 45% of the oil is collected, and the remaining 55% is disposed of improperly [33], leading to environmental pollution if not properly handled. The final component, crumb tire rubber, is obtained by shredding waste tyres, a significant concern considering the global disposal of approximately 800 million tires annually (Yan, 2020). The market value of recycling these tires was projected at $5.12 billion in 2021, predicted to increase by 3.5% annually from 2022 to 2031. This growth will lead to a market size of $7.32 billion by 2031 (Allied Market Research, 2021). Ergo, adopting modified bitumen is potentially a sustainable solution for the road construction industry, considering the rising demand for bitumen and the pressing environmental concerns of waste engine oil and discarded tires.

MIXING AND PROPORTIONING OF MATERIALS

In this study, 24 samples have been proportioned by replacing waste engine oil and crumb tyre rubber in bitumen. The partial replacement has been mixed with the base bitumen (grade-80/100) using the shear mixer for 20 minutes at the base bitumen's production temperature (150°C). The composition of the WEO utilized in this phase ranged from 3% to 9%. Further, the WEO binder was replaced with crumb rubber in the shear mixer at 160°C-180°C for 45 minutes. The crumb tyre rubber concentrations varied from 5% to 15% throughout the mixing process. The bitumen content has been replaced from 8 % in MB-1 to 24% in MB-24. The proportion of samples has been shown in Table 1.

TABLE 1. Mix Proportions

Sample No.	% WEO	% CTR	WEO (gs)	CTR (gs)	VB (gs)
VB	0	0	0	0	300
MB-1	3	5	9	15	276
MB-2	3	7	9	21	270
MB-3	3	9	9	27	264
MB-4	3	11	9	33	258
MB-5	3	13	9	39	252
MB-6	3	15	9	45	246
MB-7	5	5	15	15	270
MB-8	5	7	15	21	264
MB-9	5	9	15	27	258
MB-10	5	11	15	33	252
MB-11	5	13	15	39	246
MB-12	5	15	15	45	240
MB-13	7	5	21	15	264
MB-14	7	7	21	21	258
MB-15	7	9	21	27	252
MB-16	7	11	21	33	246
MB-17	7	13	21	39	240
MB-18	7	15	21	45	234
MB-19	9	5	27	15	258
MB-20	9	7	27	21	252
MB-21	9	9	27	27	246
MB-22	9	11	27	33	240
MB-23	9	13	27	39	234
MB-24	9	15	27	45	228

PENETRATION TEST

This test has been performed to assess the hardness of VB & WEO-CTR-MB. As per the AASHTO designation 49-74 standard, the test involves penetration of a standard needle into the bitumen sample under a specific load, time, and temperature conditions. The penetration depth is measured in tenths of a millimetre and is called the penetration value. The test is commonly used to determine the suitability of bitumen for different climatic conditions and traffic loads. A higher penetration value indicates softer bitumen, while a lower value indicates harder bitumen. The test results are crucial in selecting the appropriate grade of bitumen for road construction and estimating the expected performance of the asphalt pavement.

SOFTENING POINT TEST

The softening point test, classified as a consistency test, designated as AASHTO T 53-4, is a standard test method for determining the softening point of bitumen using the ring-and-ball apparatus. The test measures the temperature at which a bitumen sample loaded with a steel ball reaches a specific deformation level under controlled heating and loading conditions. The softening point is a significant parameter in the characterization of bitumen, as it indicates the temperature range over which the bitumen will perform satisfactorily in asphalt mixtures. The test procedure involves placing a small bitumen sample in a metal ring, then suspended in a glycerine or silicone oil bath. A steel ball is placed on top of the sample. The temperature gradually increases at 5°C per minute until the bitumen softens enough to allow the ball to sink a specified distance into the sample. The temperature at this point is recorded as the softening point. The test is widely used in the asphalt industry to assess bitumen's quality and ensure that it meets the necessary specifications for use in pavement construction.

FLASH AND FIRE POINT TEST

The test has been conducted to determine the temperature threshold below which fire hazards must be avoided when operating the WEO-CTR-MB for pavement construction. The test has been carried out per AASHTO Designation: T 73-74 and D 93-72. The test involves heating a substance sample in a closed cup apparatus and observing the temperature at which the substance produces enough vapor to ignite in an external flame. The lowest temperature at which the substance produces enough vapor to ignite is known as the flash point. The temperature at which the substance continues to burn after ignition is known as the fire point. The results of this test are used to determine the appropriate handling, storage, and transportation of the substance.

DUCTILITY TEST

The ductility test has been performed to determine the ductility of WEO-CTR-MB at a specified temperature and rate of pulling. The test is conducted according to the AASHTO Designation: T 5-74, which outlines the procedure for measuring the elongation of a briquette of bitumen. First, a sample of the bituminous material is molded into a briquette of a standard size and shape using a briquette mold and then cooled to a specified temperature before being placed in the testing machine. The machine consists of a set of clamps that hold the briquette in place. The test machine pulls the briquette apart at a constant speed, and the distance the briquette stretches before breaking is measured as the ductility of the sample. This test is important in determining the elasticity and flexibility of the bitumen in the specific climate condition.

SPECIFIC GRAVITY TEST

The specific gravity test of bitumen is a method to determine the density or mass per unit volume of bitumen. The determination of impurities present in bitumen is a key factor in evaluating its properties and purity, which is possible through the Specific Gravity Test. If the replacement material used, such as CTR and WEO, has a lower specific gravity, the specific gravity of the modified bitumen will decrease correspondingly. The test has been performed according to AASHTO T 228 standards. In this test, a bitumen sample is heated and poured into a known volume container. The container is then weighed, and the specific gravity of the bitumen is calculated as the ratio of the weight of the bitumen to the weight of an equal volume of water. The specific gravity of virgin bitumen ranges from 0.97 to 1.02. This test provides important information about bitumen's consistency, hardness, and durability, which are essential for selecting suitable bitumen for different applications.

RESULTS AND DISCUSSION

PENETRATION TEST

Figure 1 illustrates that the penetration value (0.1 mm) for virgin bitumen is 82, while for the 3% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding penetration values are 98.5, 94, 91.5, 89, 87, and 83.5, respectively. The corresponding penetration values for the 5% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture are 116, 112, 109, 106.5, 102.5, and 101, respectively. The corresponding penetration values for the 7% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture are 132, 127, 119, 117.5, 116.5, and 115, respectively. Finally, for the mixture of 9% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR, the penetration values are 146, 141, 135, 132, 131.5, and 126, respectively. The lowest penetration value is observed for 3% WEO and 15% CTR blend, and the highest is for 9% WEO and 5% CTR.

Bitumen is mainly composed of asphaltenes suspended in a maltene matrix. The CTR, which is rich in asphaltenes, hardens the bitumen. Hence, the results show a decrease in bitumen grade when crumb tyre concentration is increased in the mix. Additionally, the results show that WEO oil reduces the penetration values of bitumen. This can be ascribed to the fact that WEO is rich in maltenes (Fernandes, 2018), increasing modified bitumen's consistency, making it more suitable for operational use, and improving its deformation and fatigue resistance (Shi, 2023). Overall, the findings demonstrate that the addition of CTR and WEO significantly affects the penetration values of modified bitumen.

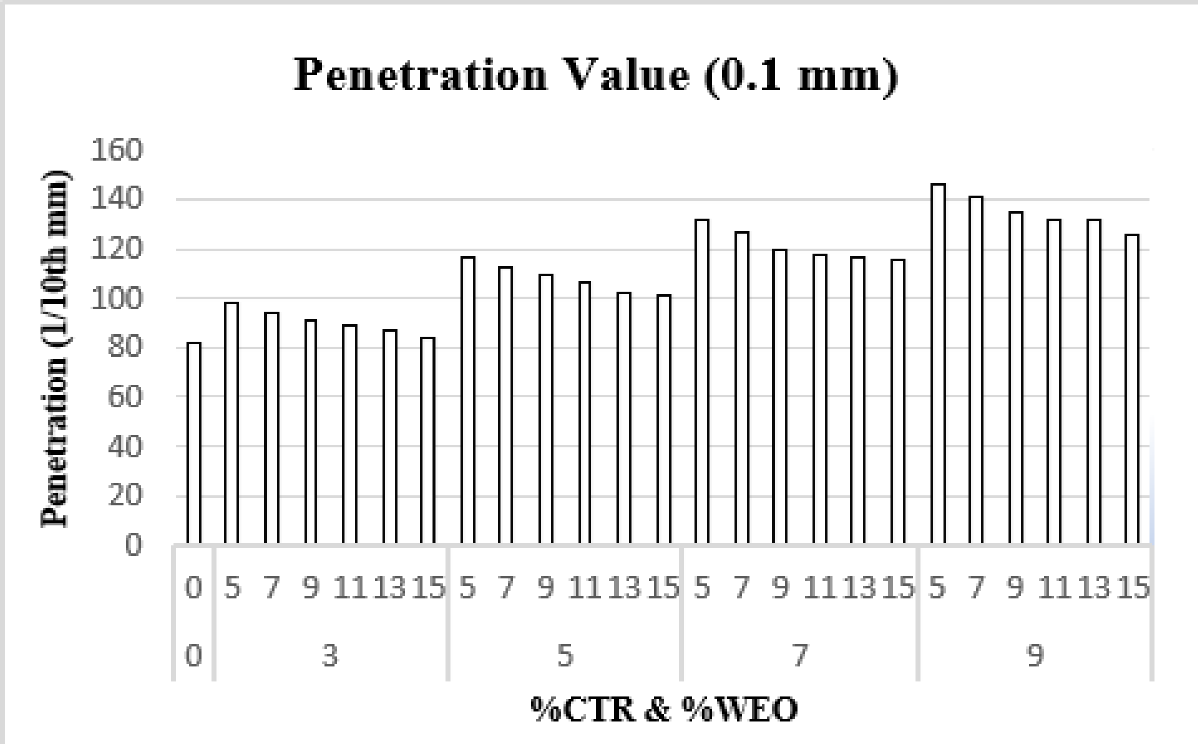

FIGURE 1. Penetration Test

PENETRATION INDEX

The Penetration Index (PI) is a dimensionless empirical value that measures how bitumen responds to changes in temperature. It is commonly used to predict the behavior of bitumen and determine the type of bitumen that is suitable for a given climate condition. Various equations exist to define how viscosity or consistency changes with temperature, and the Pfeiffer and Van Doormaal equation is one such example (Pfeiffer, 1936). In this study, this equation has been used to determine the Penetration Index of VB and WEO-CTR-MB at 25°C.

$$PI = \frac{1952 - 500\log P_{25°C} - 20SP}{500\log P_{25°C} - SP - 120} \quad (1)$$

Table 2 shows the PI values of VB and WEO-CTR-MB. Typically, penetration index values range from around -3 for highly temperature-susceptible bitumen to around +7 for highly blown bitumen, with low temperature-susceptible bitumen having a high PI. For paving grade bitumen used for highways, the literature suggests that typical asphalts have PI values between +2 and -2.

A lower PI value suggests that the binder changes its consistency more rapidly as the temperature changes, indicating greater temperature sensitivity. the results of the study reveal that PI values are within the normal paving range for WEO concentrations of 3%, 5%, and 7%. However, for the 9% WEO concentration mixture, the PI values are slightly lower than normal range, indicating high temperature susceptibility.

The results of this study further indicate that as the concentration of CTR increases, the PI value also increases, signifying a higher degree of temperature susceptibility for the modified bitumen. In contrast, the results demonstrate that an increase in the concentration of WEO is associated with decreasing trend in the PI value, pointing towards a lower degree of temperature susceptibility.

TABLE 2. Penetration Index (PI) Value

Sample No.	% WEO	% CTR	S.P °C	$P_{25°C}$ 0.1 mm	PI
VB	0	0	46.5	82	-0.92
MB-1	3	5	49.5	98.5	0.5
MB-2	3	7	50.5	94	0.62
MB-3	3	9	51	91.5	0.67
MB-4	3	11	53	89	1.09
MB-5	3	13	55.5	87	1.63
MB-6	3	15	56.5	83.5	1.73
MB-7	5	5	48.5	116	0.77
MB-8	5	7	49.5	112	0.93
MB-9	5	9	51	109	1.25
MB-10	5	11	52.5	106.5	1.57
MB-11	5	13	54	102.5	1.82
MB-12	5	15	55.5	101	2.13
MB-13	7	5	46	132	0.47
MB-14	7	7	48.5	127	1.1
MB-15	7	9	49	119	1.01
MB-16	7	11	51.5	117.5	1.66
MB-17	7	13	52	116.5	1.76
MB-18	7	15	54	115	2.23
MB-19	9	5	36	146	-3.14
MB-20	9	7	37	141	-2.77
MB-21	9	9	37.5	135	-2.68
MB-22	9	11	38	132	-2.53
MB-23	9	13	39	131.5	-2.12
MB-24	9	15	39.5	126	-2.05

SOFTENING POINT TEST

Figure 2 illustrates the trend of the softening point for WEO-CTR-MB, showing the temperatures at which the mixture will soften under various mix ratios. The laboratory results show that the softening temperature for virgin bitumen is 46.5°C, whereas for modified bitumen with 3% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR, the corresponding temperatures for softening point are 49.5°C, 50.5°C, 51°C, 53°C, 55.5°C, and 56.5°C, respectively. For 5% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding temperatures for softening point are 48.5°C, 49.5°C, 51°C, 52.5°C, 54°C, and 55.5°C, respectively. For 7% WEO, and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding temperatures for softening point for modified bitumen were observed as 46°C, 48.5°C, 49°C, 51.5°C, 52°C, and 54°C, respectively. Finally, for 9% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR, the corresponding temperatures for softening point are 36°C, 37°C, 37.5°C, 38°C, 39°C, and 39.5°C, respectively. Contrary to the penetration trend, the highest softening temperature value (56.5°C) is for 3% WEO and 15% CTR, and the highest softening temperature value (36°C) is for 9% WEO and 5% CTR.

The laboratory results indicate that an increase in the proportion of waste engine oil (WEO) in the mixture leads to a decrease in the softening temperature. This may be attributed to the fact that the addition of waste engine oil increases the content of maltenes to asphaltenes ratio in the mixture. Maltenes are fractions that contain smaller carbon chains and are more likely to soften at a lower temperature. On the other hand, an increase in the concentration of CTR in the mixture increases the softening point. This is because the incorporation of CTR increases the concentration of asphaltenes, which are heavier fractions of carbon (>C_{70}) that soften at higher temperatures. Therefore, it can be inferred that the bitumen is relatively stiff for a lower concentration of WEO and a higher concentration of CTR, thereby having a higher softening point.

FLASH AND FIRE POINT TEST

Figures 3 and 4 demonstrate the observations of the flash and fire point values of WEO-CTR-MB. The laboratory results indicate that the flash and fire point of the virgin bitumen are 282°C and 294°C, respectively. For modified bitumen with 3% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding temperatures for flash and fire points are 310°C and 326°C, 312°C and 331°C, 315°C and 337°C, 316°C and 344°C, 318°C and 350°C, and 324°C and 353°C, respectively. For modified bitumen with 5% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding flash and fire point temperatures are 293°C and 316°C, 296°C and 323°C, 301°C and 331°C, 303°C and 336°C, 307°C and 344°C, and 314°C and 355°C, respectively. For 7% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture resulted in the corresponding flash and fire point values of modified bitumen as 281°C and 303°C, 285°C and 311°C, 287°C and 316°C, 288°C and 320°C, 291°C and 326°C, and 301°C and 340°C, respectively. Finally, for modified bitumen with 9% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding flash and fire point values are 272°C and 286°C, 277°C and 294°C, 279°C and 299°C, 282°C and 307°C, 285°C and 314°C, and 302°C and 329°C, respectively. The increase in concentration of WEO in bitumen mixture results in an increase in flash and fire point temperatures, possibly due to the lower flash and fire temperatures of WEO, while an increase in the concentration of CTR in modified bitumen mixture raises flash and fire points due to the higher softening temperature of CTR. Since the results of the flash and fire tests are within the safe limits, the WEO-CTR-MB is a risk-free product for operation, making it safer during transportation, storage, and application. The higher these values are, the less likely the material is to ignite and cause a fire. This is especially important while transporting bulk quantities, storage in large tanks, and installation using a propane torch. The increased safety benefits of modified bitumen reduce the risk of fires and explosions, which can have disastrous consequences in industrial settings and construction operations.

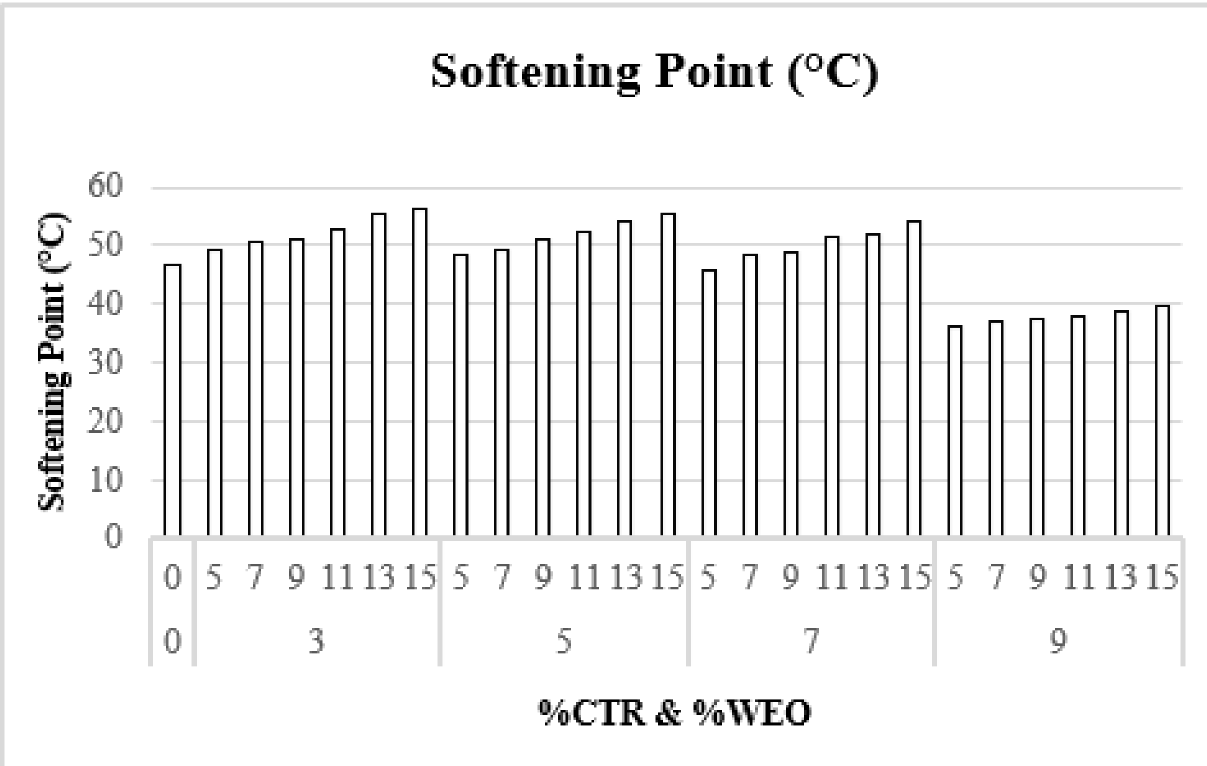

FIGURE 2. Softening Point

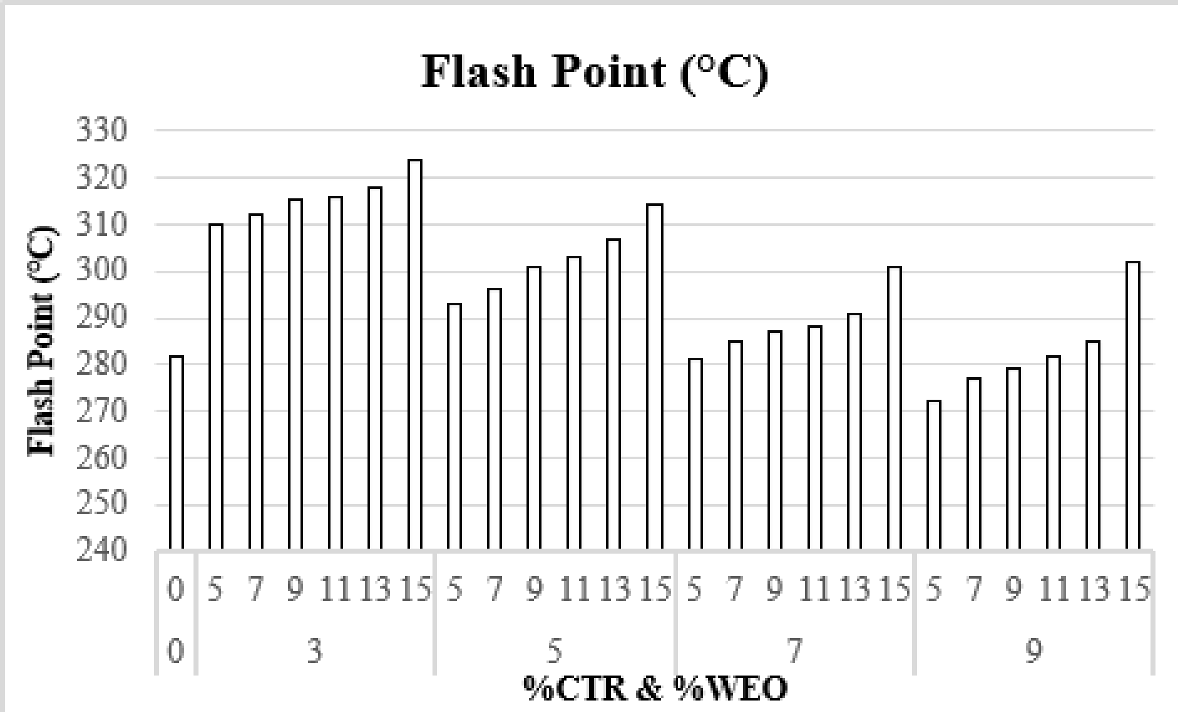

FIGURE 3. Flash Point

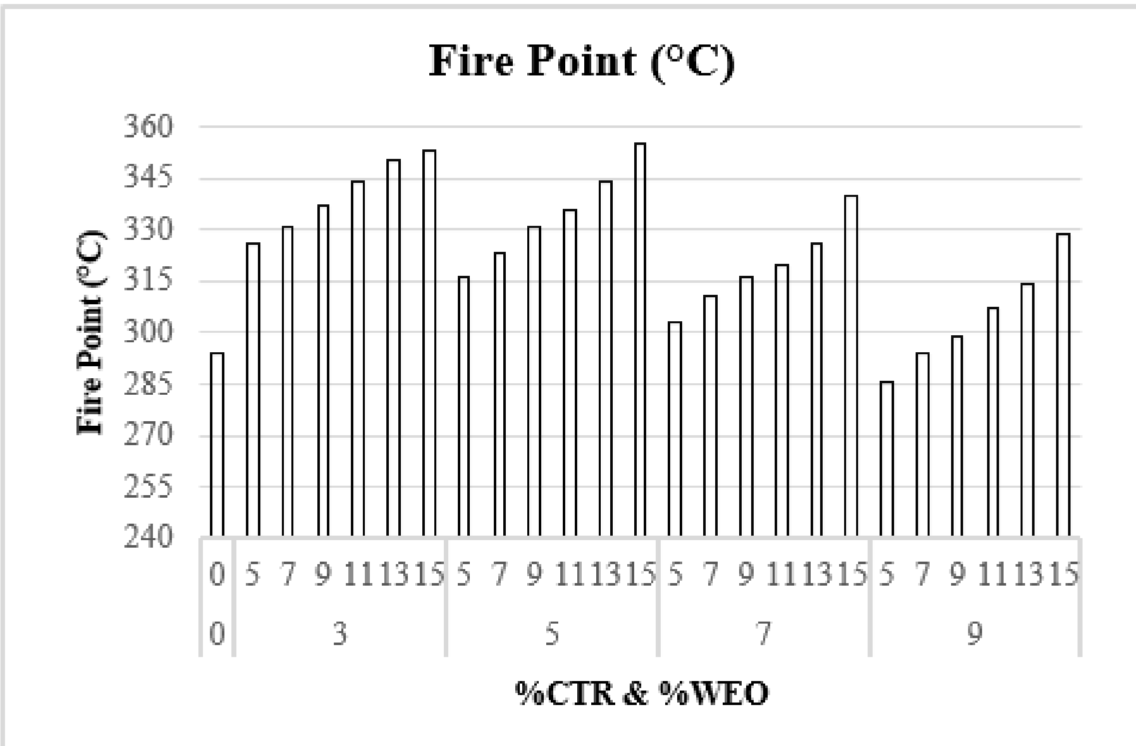

FIGURE 4. Fire Point

DUCTILITY TEST

Figure 5 provides a graphical representation of the ductility test observations for virgin and modified bitumen. The ductility value (cm) of virgin bitumen is 102.7, while for modified bitumen with 3% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR replacement, the corresponding ductility values are 41.5, 40.8, 39.2, 39, 37.6, and 36, respectively. For modified bitumen with 5% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR replacement, the corresponding values for ductility are 35.4, 34.7, 33.2, 30.1, 31, and 30, respectively. For modified bitumen with 7% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR replacement, the corresponding ductility values were observed to be 28.9, 27.8, 26.9, 25.7, 24.6, and 24, respectively. Finally, the corresponding ductility values of modified bitumen with 9% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR replacement were 23.5, 21.4, 20.7 19.3, 19, and 20.1, respectively. The laboratory observations indicate that bitumen has significantly lost its ductility when mixed with WEO and CTR. The ductility of WEO-CTR-MB decreases with an increase in the proportion of WEO and CTR replacement. Moreover, it is essential to note that the lack of ductility is not necessarily an indication of poor bitumen quality (Jeong, 2010), as the suitability of the modified bitumen will depend on the specific application and the conditions in which it will be used. Properties like stiffness, viscosity, and temperature susceptibility are essential factors to evaluate the modified bitumen's suitability for a specific application.

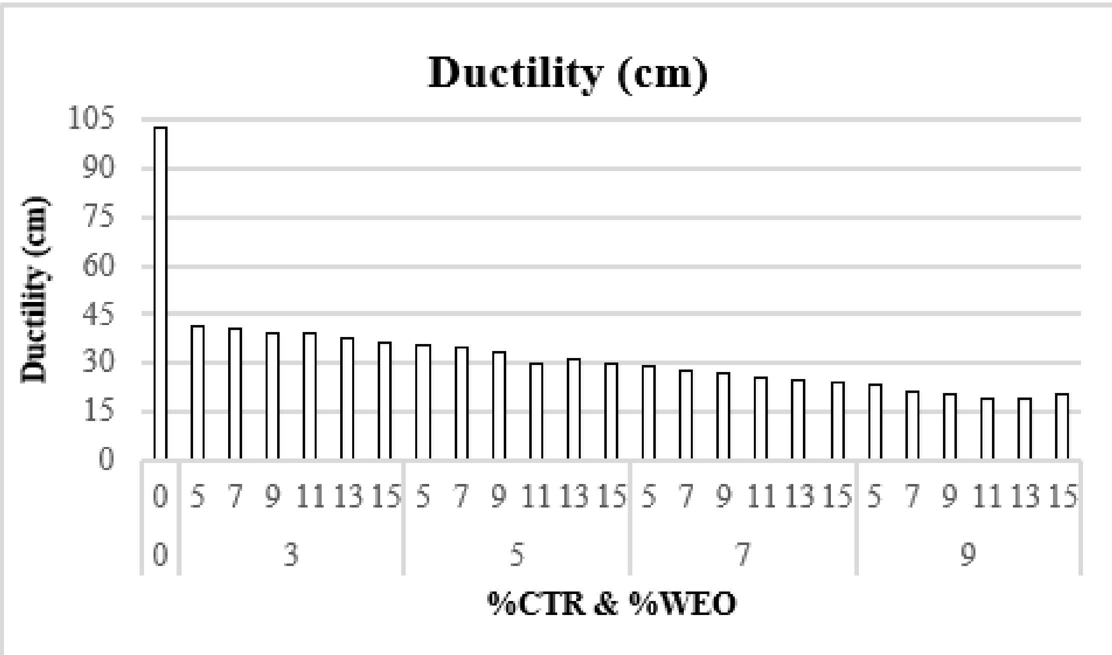

FIGURE 5. Ductility

SPECIFIC GRAVITY TEST

Figure 6 illustrates the specific gravity values for virgin and modified bitumen. For virgin bitumen, the specific gravity value is 1.016. However, for 3% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding specific gravity values are 0.996, 0.987, 0.984, 0.982, 0.977, and 0.973, respectively. Similarly, for 5% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR, the specific gravity values are 0.997, 0.989, 0.986, 0.981, 0.974, and 0.971, respectively. For 7% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding specific gravity values for modified bitumen were observed to be 0.994, 0.983, 0.98, 0.978, 0.973, and 0.972, respectively. Finally, for 9% WEO and 5%, 7%, 9%, 11%, 13%, and 15% CTR mixture, the corresponding specific gravity values are 0.992, 0.984, 0.981, 0.978, 0.973, and 0.967, respectively. Adding WEO and CTR to bitumen mixtures decreases specific gravity, possibly due to the lower density of WEO and CTR compared to VB. These observations indicate that adding waste materials to bitumen can affect its physical properties, impacting the performance of asphalt mixtures. Therefore, it is important

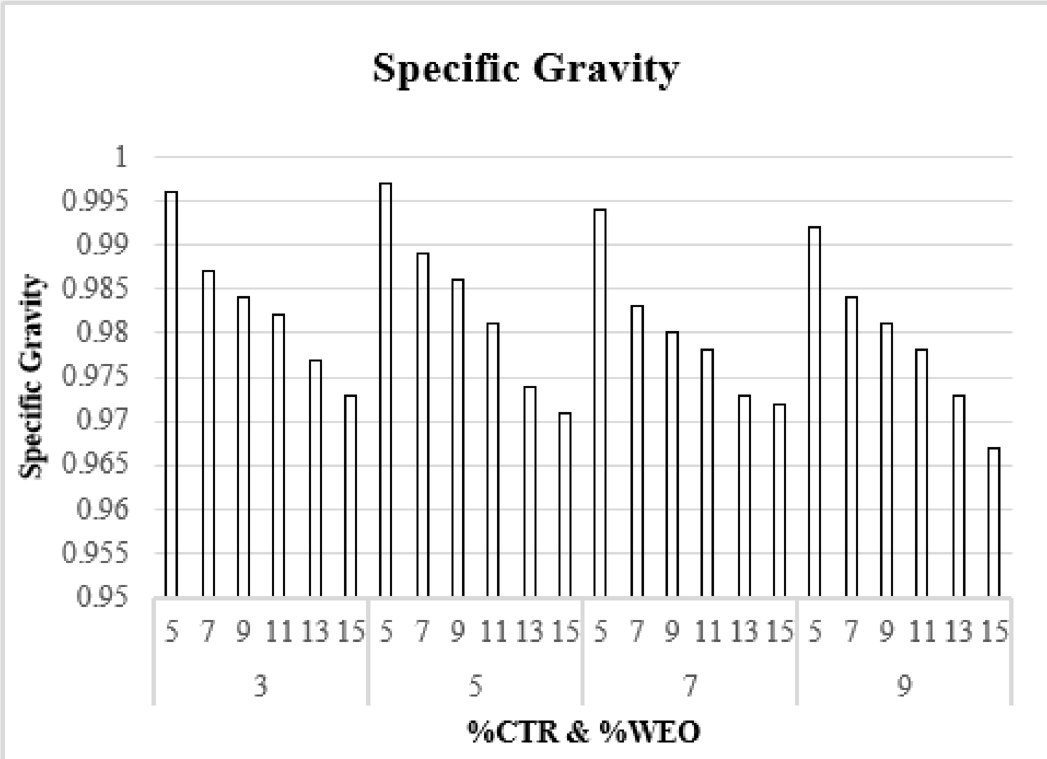

FIGURE 6. Specific Gravity

to carefully select and evaluate the waste materials used in bitumen modification to ensure the desired properties are achieved.

CONCLUSION

Different concentrations of WEO and CTR have been mixed with virgin bitumen and tested for physical characteristics such as penetration, softening point, flash and fire point, ductility, and specific gravity. The observations show a synergetic effect as adding WEO to the bitumen decreases the softening temperature and increases the penetration value of the virgin bitumen. Similarly, it has been observed that adding CTR in the bitumen reduces the penetration value and increases the softening temperature. Furthermore, PI values obtained in this study fall within the typical range for paving grade bitumen, indicating that the modified bitumen can be effectively utilized in different climate conditions.

Moreover, the flash and fire point values have increased after modification, while the ductility and specific gravity values have decreased. The blend consisting of 5% CTR and 9% WEO has the highest penetration value among all the samples tested, making it suitable for reducing excessive brittleness in bitumen. This blend may be used to reduce rutting and suggests the economic benefits of modified bitumen leading to sustainable pavements. Additionally, adding CTR in the bitumen has increased the softening point value. The blend prepared with 15% CTR and 3% WEO has the highest softening temperature. The ductility value has decreased significantly with increased WEO and CTR concentrations. The blend with the highest ductility value (41.5 cm) is 3% WEO and 5% CTR. Furthermore, the flash and fire point value for all the mixes have improved, and all are within safe limits of operating with HMA, ensuring the safe operation of WEO-CTR-MB modified bitumen. The specific gravity value for all the samples has decreased. A similar trend of penetration, softening point, ductility, specific gravity, and flash and fire point results has been seen when CR has been used with Bio-oil (Jeong 2010). Observations indicate a range of bitumen grades suitable for use in varying climate conditions. The modified bitumen using WEO and CTR has been successfully developed, and the resulting properties vary depending on the blend used for modification, with most blends exhibiting improved performance compared to commercially available bitumen.

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DECLARATION OF COMPETING INTEREST

None

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