

Investigation of the Impact of Waste Engine Oil and Coconut Fiber on the Physical Characteristics of Bitumen.

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Abstract

The modification of virgin bitumen has been an active area of research, aiming to enhance its performance characteristics. This study explores the synergistic effects of incorporating waste engine oil (WEO) and coconut fiber (CF) as bitumen modifiers. The results displayed a synergetic effect as adding waste engine oil increases the penetration and ductility while decreasing the softening temperature of the virgin bitumen. Conversely, the inclusion of coconut fiber reduces the penetration and ductility but increases the softening temperature. The mix consisting of 2% coconut fiber and 9% waste engine oil possessed a high penetration value, suggesting its potential to minimize excessive bitumen brittleness. Furthermore, the mix with 6% coconut fiber and 3% waste engine oil exhibited a high softening point, which could mitigate rutting. Additionally, the overall ductility test results and the specific gravity have decreased, while the flash and fire point values have improved significantly, ensuring the safe operation of the waste engine oil-coconut fiber modified bitumen (WEO-CF-MB). The outcome of this research demonstrates that these agro-industrial wastes can efficiently improve the physical properties of bitumen, leading to enhanced durability, better functioning, and increased eco-friendly road construction practices.

Keywords: Modified bitumen; waste engine oil; coconut fiber; physical properties; green roads.

1. Introduction

Bitumen is a refined mixture of organic liquids with a high viscosity, a black color, and a sticky consistency [1]. Bitumen is a very useful material in construction practices and it is usually used as paving or waterproofing material due to its non-porous nature. The high durability, weathering resistance, and flexible nature of bitumen make it ideal for paving practices. Over 121 million metric tons of asphalt are needed annually to meet global demand [2]. This entails a significant financial and labor investment, which goes towards maintaining and updating the current pavements [3]. The manufacturing of bitumen for asphalt mixtures makes the paving industry one of the top consumers of fossil fuel in the construction sector particularly related to the consumption of bitumen [4]. Currently, one of the major problems faced by the pavement industry is the rapid and enormous increase in the number of vehicles on the roads, which has caused increased stresses

on the pavement directly causing the deterioration of roads due to increased deformations and fatigue. Moreover, the extensive production and use of bitumen pose environmental concerns because of its increased carbon footprint and higher risk of pollution. To address this issue, it is necessary to use appropriate and sustainable additives to reduce the bitumen content in mixes and minimize its global impact [5]. On the contrary, the amount of waste engine oil (WEO) being produced globally is rising along with the number of automobiles on the road. The WEO has the potential to be used in the construction of highways because of its molecular similarity to bitumen. [6]. Increasing waste engine oil production around the globe is a major concern due to its hazardous and polluting nature. The compounds found in waste engine oil significantly damage the environment. However, the similarity in the molecular structure of waste engine oil and bitumen is a good reason why it can be considered a great additive and filler in bitumen mixes to reduce its content. waste engine oil contains asphaltenes which are the major compounds that make up bitumen. The induction of waste oil in bitumen can help us create better and cleaner bitumen with a lower carbon footprint and less environmental damage. In addition to that, the waste produced from coconut production accounts for 20 - 25% of the total volume of the production. This waste is known as coir which is left behind is either burned in mass quantities which causes a release of toxic gases in the atmosphere, or it is dumped in lakes or landfills where it starts to accumulate and cause blockages in rivers or channels. Coconut coir is a strong and durable material due to its fibrous nature, making it an ideal additive to bitumen. The strands of fiber in the coir cause it to form a matrix of reinforcement within the bitumen and provide adequate strength. Coir fiber is inexpensive, but it's also robust and long-lasting [7]. Coconut fiber is already being utilized in construction applications due to its flexible yet durable nature. The induction of coconut coir in bitumen will help to reduce the bitumen content while it imparts strength and stiffness in return. When combined with an asphalt mixture, coconut fiber offers several benefits, including the ability to lessen binder bleeding and improve the coating's macrotexture. It can aid in surface drainage improvement and mechanical property reform." [8]. Therefore, this study uses a combination of agro-industrial waste as a suitable additive in bitumen to observe the changes in its physical properties, which is potentially an eco-friendly, energy-efficient, and economical approach.

The construction and maintenance of road infrastructure are critical for economic development, and the performance of asphalt pavements largely depends on the properties of bitumen. Traditional bitumen, while effective, often suffers from issues such as temperature susceptibility, aging, and cracking under stress. Recent research has focused on modifying bitumen using various additives to enhance its performance characteristics. Among these, waste engine oil (WEO) and coconut fibers (CF) have emerged as promising materials for bitumen modification. The primary goals of bitumen modification are to enhance its durability, elasticity, and resistance to temperature fluctuations and aging. Furthermore, waste engine oil is a by-product of vehicle maintenance and is often considered hazardous due to its environmental impact. However, it contains valuable components that can rejuvenate aged bitumen. WEO is rich in maltenes and lighter fractions of bitumen that contribute to its viscoelastic properties. It has been found that adding WEO to aged asphalt significantly improved its penetration and ductility, which are critical for flexibility and resistance to cracking [4]. Moreover, the softening point is an essential parameter that indicates the thermal susceptibility of bitumen. The addition of WEO decreased the softening point of bitumen. The viscosity of the modified bitumen was also reduced, which enhances workability during application [9]. However, the chemical composition of WEO plays a crucial role in its effectiveness as a modifier. The presence of functional groups such as carbonyl and sulfoxide in WEO can interact with the polar components of bitumen, leading to improved adhesion and cohesion within the asphalt

matrix. This interaction can mitigate the effects of aging and enhance the overall durability of the pavement [10]. Utilizing WEO for bitumen modification not only addresses waste management issues but also contributes to sustainable construction practices. By recycling waste oil, the demand for virgin bitumen is reduced, leading to lower energy consumption and greenhouse gas emissions during production [11]. Furthermore, the economic viability of using WEO is evident in the potential cost savings associated with reduced material requirements and improved performance of the asphalt mixtures. In addition to that, Coconut fibers, derived from the husk of coconuts, are abundant, biodegradable, and possess excellent mechanical properties. Their fibrous structure reinforces the bitumen matrix, enhancing its overall performance. Coconut fibers are rich in cellulose, lignin, and hemicellulose, which contribute to their strength and durability. The incorporation of coconut fibers into bitumen has been shown to improve its mechanical properties significantly. [12] He reported that the addition of coconut fibers increased the Marshall stability of hot mix asphalt (HMA) by up to 41%, indicating enhanced resistance to deformation under load. The fibers contribute to the cohesion of the asphalt matrix, which is crucial for maintaining structural integrity under heavy traffic loads. Coir fiber has been recognized for its high tensile strength, durability, and resistance to moisture, making it an attractive option for enhancing the properties of asphalt mixtures. The utilization of coir fiber as an asphalt modifier reported significant improvements in the mechanical properties of the modified asphalt, including increased stability and reduced deformation under load. The importance of fiber content and length in achieving optimal performance suggested that a coir fiber content of 0.5% by weight of the asphalt binder yielded the best results in terms of stability and flow values [13]. Moreover, it has been found that the addition of coir fiber improved the mechanical properties of asphalt mix, such as stability and resistance to deformation which supports the viability of coir fiber as a sustainable additive that can enhance the performance of asphalt mixtures while reducing the environmental impact associated with traditional modifiers [3]. Furthermore, the inclusion of coir fiber improved the permeability and drainage characteristics of the asphalt mixtures, making them suitable for use in porous pavement applications [14]. The addition of coir fiber significantly increased the viscosity and elasticity of the asphalt binder, leading to improved high-temperature performance and reduced susceptibility to rutting which emphasized the importance of fiber distribution and orientation in achieving optimal performance, suggesting that a uniform dispersion of coir fibers within the asphalt matrix is essential for maximizing the benefits of modification [15]. Furthermore, during the thermal analysis of coir fiber, it was observed that it starts to thermally degrade at around 200°C and the degradation happens between 200-360°C, which is linked to the thermal breakdown of hemicellulose compounds in the fiber [16]. Coconut fiber can potentially improve the durability and longevity of asphalt pavements, particularly in regions with extreme weather conditions. The integration of coir fiber into asphalt technology enhances the performance and sustainability of pavement materials [17]. The combined use of WEO and CF in bitumen modification has been explored to leverage the benefits of both materials. Preliminary studies suggest that this synergistic approach can lead to improved performance characteristics compared to using either material alone. The WEO acts as a rejuvenator, restoring the properties of aged asphalt, while the coconut fibers provide mechanical reinforcement.

2. Materials and Methods

This study uses a 60/70 grade bitumen binder, Waste engine oil without any prior treatment, and coconut fiber shredded in a size of 2-10mm. The present work includes the proportioning of 9 samples by substituting waste engine oil and coconut fiber in bitumen. The partial replacement has been blended with the base bitumen (grade-60/70) using a shear mixer for 20 minutes at the typical production temperature of the bitumen (150°C).

The content of the WEO used in this study ranged between 3% to 9%. Furthermore, the WEO binder was substituted with coconut fiber in the shear mixer at temperatures ranging from 150°C to 160°C for 20 minutes. Throughout the mixing operation, the Coconut fiber concentrations ranged from 2% to 6%. The distribution of samples has been demonstrated in Table 1.

Table 1. Mix Proportions

SAMPLE No.	%WEO	%CF	WEO (gm)	CF (gm)	Virgin Bitumen (gs)
VB	0	0	0	0	300
WEO-CF MIX 01	3	2	9	6	285
WEO-CF MIX 02	3	4	9	12	279
WEO-CF MIX 03	3	6	9	18	273
WEO-CF MIX 04	6	2	18	6	276
WEO-CF MIX 05	6	4	18	12	270
WEO-CF MIX 06	6	6	18	18	264
WEO-CF MIX 07	9	2	27	6	267
WEO-CF MIX 08	9	4	27	12	261
WEO-CF MIX 09	9	6	27	18	255

2.1 Physical Characteristics Analysis

2.1.1 Penetration Test

A penetration test has been conducted to evaluate the properties of VB and WEO-CF MB. According to the AASHTO designation T-49 standard, the test entails inserting a standard needle into the bitumen sample while applying a predetermined load, at a particular duration, and temperature. The penetration depth is quantified in tenths of a millimeter and is referred to as the penetration value. This test is frequently employed to assess the suitability of bitumen for various climatic conditions and traffic loads. These test results are essential for choosing the suitable bitumen grade for road building and predicting the anticipated performance of the asphalt surface.

2.1.2 Ductility Test

Ductility testing was conducted to assess the ductility of WEO-CF-MB under specific temperature and pulling rate conditions. The test is carried out in accordance with the AASHTO Designation: T 5-74, which specifies the protocols for quantifying the elongation of a bitumen briquette. Initially, a bituminous material sample is shaped into a briquette of a predetermined size and form using a briquette mold. Subsequently, it is cooled to a required temperature before being inserted into the testing equipment. The apparatus has a series of clamps that secure the briquette in position. The test machine applies a consistent force to separate the briquette and the distance the briquette extends before it

fractures is quantified as the ductility of the sample. This test is crucial for assessing the elasticity and flexibility of bitumen under particular climatic conditions.

2.1.3 Softening Point Test

The softening point test, categorized as a consistency test and defined as AASHTO T 53 4, is a widely accepted test technique used to define the softening point of bitumen by the use of the ring-and-ball apparatus. The test quantifies the temperature at which a bitumen sample, when subjected to regulated heating and loading conditions, achieves a certain degree of deformation when loaded with a steel ball. The softening point is an important characteristic in the analysis of bitumen, as it specifies the temperature range within which the bitumen will exhibit satisfactory performance in asphalt mixes. To conduct the test, a little bitumen sample is inserted into a metal ring and then immersed in a bath of glycerine or silicone oil. A steel ball is positioned just above the sample. The temperature rises steadily at a rate of 5°C per minute until the bitumen softens enough to enable the ball to descend a predetermined depth into the sample. The temperature at this location is documented as the softening thermodynamic point. This test is extensively used in the asphalt industry to evaluate the quality of bitumen and verify its compliance with the required criteria for pavement construction.

2.1.4 Flash and Fire Point Test

The test aimed to establish the temperature threshold at which fire risks should be prevented while using the WEO-CF-MB for pavement construction. The test was conducted according to AASHTO Designations T 73-74 and D 93-72. The test subjects a substance sample to heat in a closed cup apparatus and analyzes the temperature at which the substance generates sufficient vapor to ignite in an external flame. The flash point refers to the minimum temperature at which a substance generates sufficient vapor to ignite. The fire point refers to the temperature at which a substance sustains combustion following ignition. These test results are utilized to ascertain the suitable management, storage, and transportation of the bitumen.

2.1.5 Specific Gravity Test

The specific gravity test of bitumen is a laboratory technique used to measure the density or quantity of bitumen per unit volume. Accurate identification of impurities in bitumen is crucial for assessing its characteristics and quality and can be accomplished using the Specific Gravity Test. Using substitute materials with lower specific gravity, such as CF and WEO, will result in a proportional decrease in the specific gravity of the modified bitumen. The test has been conducted following the AASHTO T 228 criteria. For this test, a bitumen sample is heated and then transferred into a container with a defined volume. Following the weighing of the container, the specific gravity of the bitumen is determined by dividing the weight of the bitumen by the weight of an equivalent volume of water. Typical specific gravity values for virgin bitumen vary between 0.97 and 1.02. This test yields crucial data on the consistency, hardness, and durability of bitumen, pivotal for the selection of appropriate bitumen for various uses.

3. Results

3.1 Penetration Test

Figure 1 below shows the results of Penetration tests conducted according to AASHTO T-49. These tests were conducted on virgin bitumen and modified bitumen of different ratios of waste engine oil and coconut fiber.

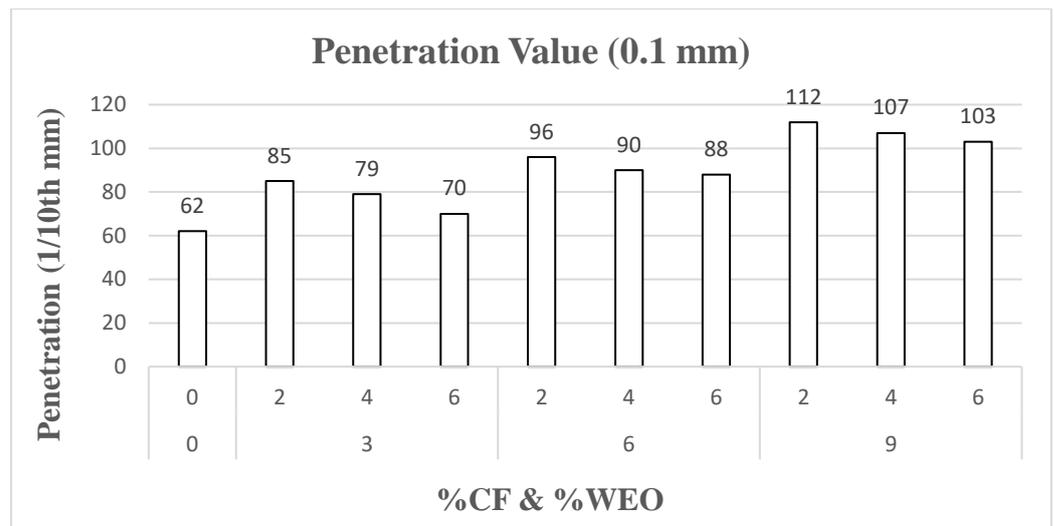


Figure 1. Penetration Test

It has been observed that the modified bitumen with 2% CF and 9% WEO gave the highest penetration value, and the modified Bitumen with 6% CF and 3% WEO gave the lowest penetration value. Moreover, the penetration value sees a downward trend as the coconut fiber content increases. This decrease is attributed to the fibrous properties of the coconut fiber, which increases the viscosity of the bitumen and hence lowers the penetration value. On the contrary, the penetration value increases as the waste engine oil content increases. This change is because waste engine oil is rich in maltenes and has low viscosity. Due to this, it improves the consistency of modified bitumen. Therefore, enhancing its suitability for practical applications results in improved resistance to deformation and fatigue [18].

3.2 Ductility Test

Figure 2 represents the ductility test observation for the virgin and WEO-CF-MB.

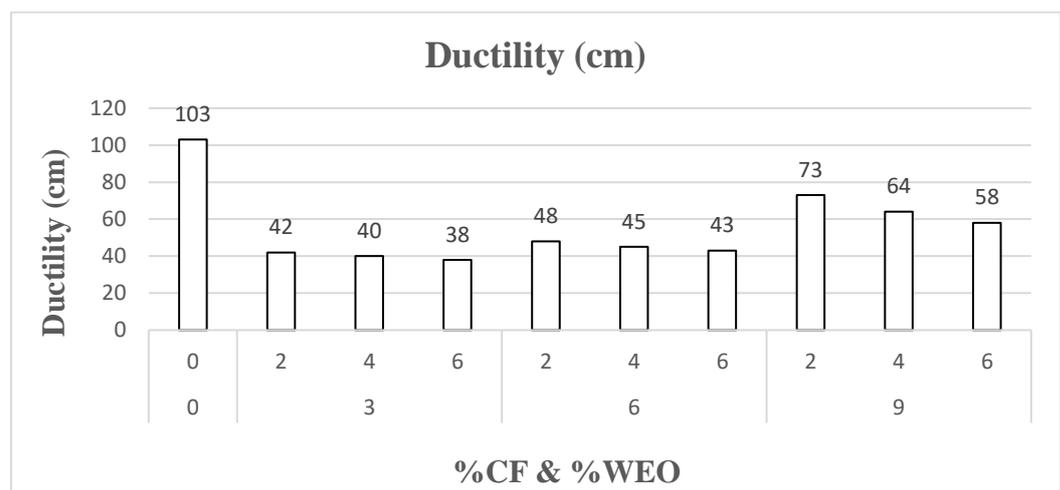


Figure 2. Ductility Test

The ductility of the Modified bitumen takes a dramatic fall from the unmodified bitumen. This may be due to the fibrous structure of the coconut fiber which acts as a reinforcement. Moreover, it has been witnessed that the ductility decreases with the increase of coconut fiber concentration and increases with the increasing content of waste engine oil. Furthermore, it is important to acknowledge that the lack of ductility does not automatically imply low-quality bitumen [19]. The appropriateness of the modified bitumen will be determined by the nature of the application and the prevailing circumstances.

3.3 Softening Point Test

Figure 3 demonstrates the trend of softening point test results for the WEO-CF-MB.

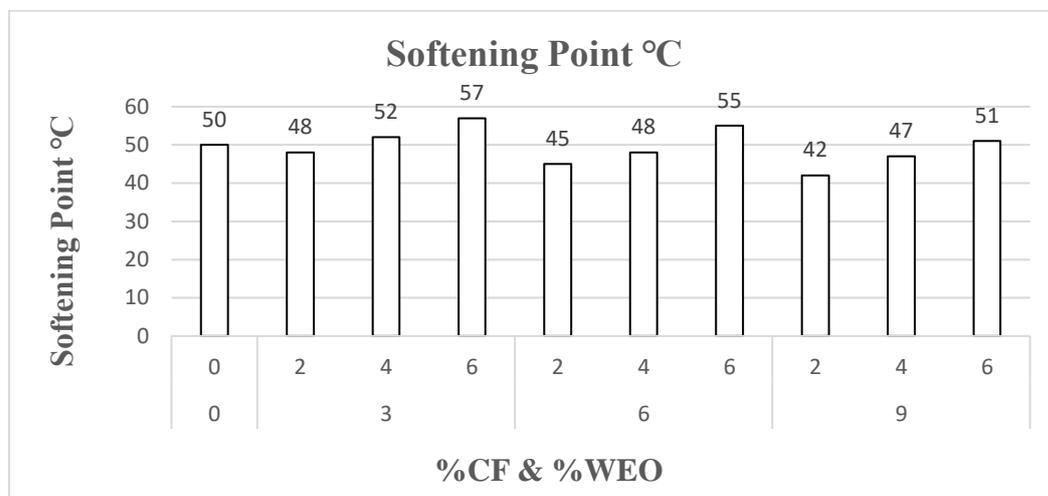


Figure 3. Softening Point Test

The experimental findings suggest that a higher concentration of waste engine oil (WEO) in the mixture resulted in a lower softening point temperature. This phenomenon may be ascribed to the fact that the inclusion of waste engine oil significantly raises the ratio of maltenes to asphaltenes in the mixture. Conversely, a higher concentration of coconut fibers (CF) in the combination leads to an increase in the softening point. Thus, it can be concluded that the bitumen exhibits a comparatively rigid behaviour when the concentration of WEO is lower and the concentration of CF is greater, resulting in a higher softening point.

3.4 Flash and Fire Point Test

Figures 4 and 5 illustrate the flash and fire point test results to determine the modified bitumen's combustibility. Flash and Fire point tests are necessary to test the optimum temperature limit for bitumen.

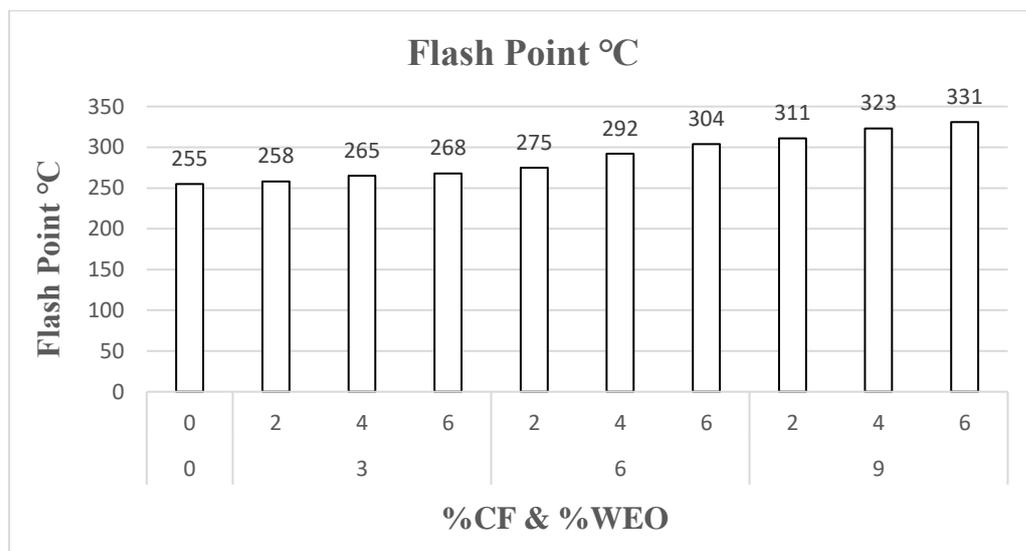


Figure 4. Flash Point Test

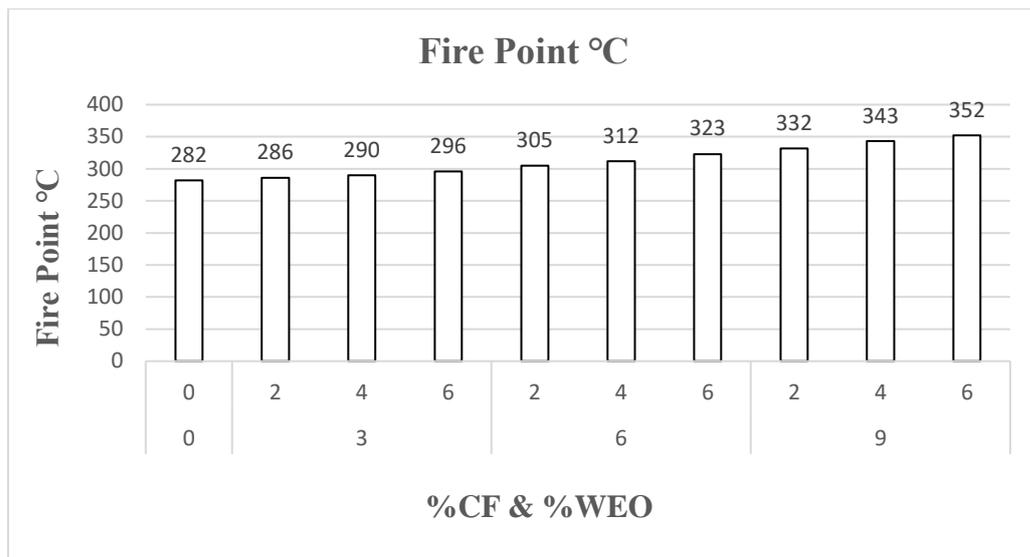


Figure 5. Fire Point Test

The flash and fire point of the bitumen kept increasing with the increasing content of WEO and CF. This implies that the resistance to combustibility of the bitumen kept increasing. There are no risks with using the WEO-CF-MB because the results of the flash and fire tests were within the acceptable ranges. This makes it safer to move, store, and use. It's less likely that the object will catch fire if these numbers are high. This is especially important when moving large amounts of it, storing it in big tanks, and in industry and building settings where they can be very dangerous.

3.5 Specific Gravity Test

Figure 6 represents the specific gravity values of virgin bitumen and WEO-CF-MB.

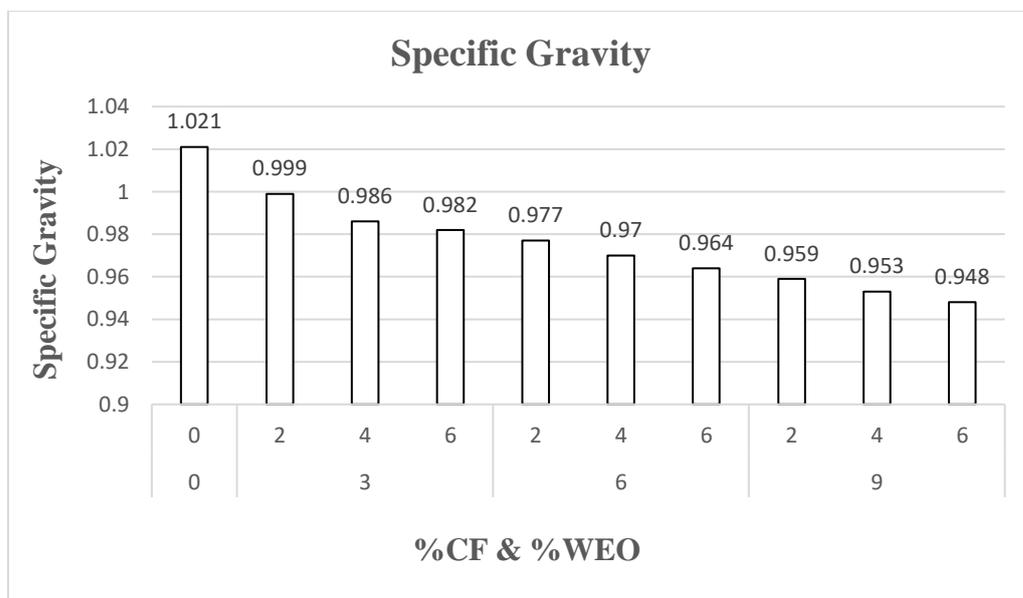


Figure 6. Specific Gravity Test

The specific gravity of the modified bitumen is shown to decrease with the addition of waste additives. The primary reason for this decrease is probably due to the low viscous properties of waste engine oil as the results suggest the addition of WEO decreases the amount or weight per unit volume of the modified bitumen. Hence, the modified bitumen is lighter than the conventional unmodified bitumen which suggests that it is important

to select the additives carefully to modify the bitumen keeping in view that the desired properties are achieved. 287
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4. Discussion 289

The modification of virgin bitumen has been done by adding WEO and CF and physical characteristics were evaluated through penetration, ductility, softening point, flash & fire point, and specific gravity test. The results displayed a synergetic effect as adding WEO increases the penetration, and ductility whereas it decreases the softening temperature of the virgin bitumen. On the other hand, the inclusion of CF decreases the penetration and ductility while it increases the softening temperature. The mix consisting of 2% CF and 9% WEO possessed a high penetration value which suggests that it could be a better option to minimize the excessive brittleness in the bitumen. Moreover, the mix consisting of 6% CF and 3% WEO possessed a high softening point. The use of this mixture has the potential to mitigate rutting and underscores the economic advantages of modified bitumen in promoting sustainable pavements. Furthermore, the overall ductility test results and the specific gravity have decreased while the flash and fire point values have improved significantly ensuring the safe operation of WEO-CF-MB. 290
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5. Conclusions 303

So, the outcome of this research proves that these agro-industrial wastes can efficiently lead to the improvement in the physical properties of bitumen. Moreover, Allowing the use of such materials can lead to enhancement in durability, better functioning, and an increase in eco-friendly road construction practices. Even though this research shows positive outcomes using WEO and CF as a modifier for bitumen grade 60/70, it is important to evaluate its other characteristics thoroughly so that it can be used widely to a larger extent. 304
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Abbreviations 322

WEO-CF MB	Waste engine oil – coconut fiber modified bitumen	323
CF	Cocout fiber	324
WEO	Waste engine oil	325
AASHTO	American Association of State Highway and Transportation Officials	326

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