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Modification in Mechanical Properties of Vg 10 Grade Bitumen by Using Waste Engine Oil and Crumb Rubber Powder

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ABSTRACT- India makes a lot of scrap tyres every year, which is bad for the environment. Recycling these tyres can help with these problems, and they can be used in many civil engineering projects, such as changing the way asphalt pavement is made. Using used rubber in asphalt mixtures has been studied a lot and shown to be possible. This work also looks into the possibility that used engine oil could be used to change bitumen in a way that is good for the environment and helps with problems related to getting older. When waste engine oil is added, problems arise, such as more rutting and less elasticity recovery. The focus of the research is on using waste materials, like CRMB waste and used engine oil, to replace some bitumen. The goal of the study is to make waste samples with different amounts of VG10 bitumen, waste engine oil, and waste CRMB. These concentrations range from 0% to 15%, which tells us a lot about how waste materials could be used to build roads.

KEYWORDS- Bitumen, Waste Engine Oil, Crumb Rubber Powder

I. INTRODUCTION

Based on the prevailing circumstances, it is evident that the global population is experiencing a steady growth trajectory, leading to a corresponding rise in the utilisation of plastic polymers, automobiles, and other related commodities. Consequently, this surge in consumption has resulted in a proportional increase in pollution, particularly in the form of waste polymers. In the realm of waste management, the decomposition of polymers encounters several notable obstacles. The proper disposal of waste materials is imperative due to their potential for long-term persistence in the environment. Failure to decompose these materials can result in their extended presence on Earth, potentially spanning several centuries. This persistence poses a significant risk, as it has the potential to exacerbate environmental pollution levels. A methodology exists for the decomposition of the aforementioned material through the process of storing or repurposing discarded products in a manner that is beneficial and practical. Ongoing research endeavours are currently being conducted to explore novel and innovative approaches for the utilisation of waste materials. Numerous private enterprises and highway authorities have undertaken a series of sophisticated investigations and initiatives aimed at incorporating waste polymers into road construction practices. These endeavors priorities environmentally sustainable approaches while simultaneously enhancing the performance of road infrastructure through the utilisation of such materials. [1,2,3] These studies are conducted with the objective of exploring methods that promote the safe and sustainable management of waste materials, as well as enhancing the cost-effectiveness of road construction practises. The surveys primarily serve to illustrate the substitution of waste materials with conventional building materials. The research endeavors revolve around the exploration and development of novel and cutting-edge inventions that harness the potential of waste materials. There is a growing apprehension surrounding the practise of reusing waste materials and utilising natural resources for the purpose of road paving, which is currently being closely monitored or subject to restrictions. Numerous research studies have been conducted to investigate the aforementioned problems, or specific aspects thereof, thereby resulting in delayed progress in this area of inquiry. The road paving industry relies heavily on the utilisation of various natural resources, including but not limited to bitumen and aggregates, in order to effectively construct and maintain road infrastructures. These resources, however, are finite in nature, meaning that their availability is limited and cannot be replenished at the same rate at which they are consumed. Consequently, it is crucial for the industry to carefully manage and optimise the use of these resources to ensure their sustainable utilisation in road construction activities. [15,17,24]

II. EXPERIMENTAL

A. Materials

This area is inspired to demonstrate the research methods used in this study. This chapter addresses explanations of the materials used. As we are aware, descriptions of the specimens and test methods are important to the experiment. The following sections also describe them in detail.

The inspection test technique was divided into three sections:

- The key aim of section one was to ensure daily bitumen properties.

- The properties of standard bitumen halfway substituted with waste motor oil are calculated in section 2.
- Section three dealt with the decision to replace the appropriate volume of waste motor oil with standard bitumen.

Aggregates, bitumen and waste engine oil are required materials for this test. A detailed discussion was conducted below concerning the appropriate material form and its properties. [7,8,9] The floor structure is a major structure and the purpose of the flooring is mainly to bear heavy loads of moving traffic and pavement structures. [13] Thus, its characteristics and efficiency are very important for the use of aggregates. Owing to the friction between pneumatic and concrete surfaces, toughness due to a variety of environmental changes and very heavy duty moving loading wheels, the aggregates must likely resist wear. The use of a large number of bituminous concrete mixtures of the different aggregates of the minerals. [4,5] Different tests were carried out in the laboratories to monitor components for construction and their performance and characteristics. It is the research technique.

- Crush test IS: 2386 (Part)-IV Crushing test
- Abrasion test Los Angeles IS: 2386 (Part)-IV
- IS impact test: 2386 (Part)-IV Impact assessment
- Soundness Test IS: 2386 (Part)-V Soundness Test
- Form research IS: 2386 (Part)-I Form testing
- General gravity and water absorption in accordance with IS: 2386(part)-III

B. Methods

Bitumen is used mainly as a binder in pavement construction. [10,11,14] The way bitumen is processed is by distilling crude oil to extract it. Bitumen is a hydrocarbon type. [6] The CCl_4 (carbon tetrachloride) and CS_2 (carbon disulphide) are a dissolved material. As mentioned above, bitumen has a high propensity to bind and is used as a waterproofing material in pavements. The determination of the use of the type of bitumen depends on whether the construction is necessary. Bitumen remains solid, non-volatile for all purposes under room temperature. The vapor pressure in situ is below the reason for the recognition of typical composition. The viscosity property is used to grade various forms of bitumen. The bitumen rating used in this analysis for the experiment is VG 10. The performance and characteristics of bitumen were assessed following research.

- Check of the softening point as per IS: 1205-1978
- IS: Standards 1203 1978 have been introduced i.e. Indian standard system for measuring bituminous substances: the penetration measurement (first review) bitumen used is 80/100
- The Indian standard way of measuring bituminous materials is 1208 1978: Ductility determination (first revision) used as VG 10. • IS: 1208 1978
- IS Gravity test: 1202-1978 Specific Gravity test

Motor oil is a useful asset. The hydrocarbon base obtained from nature's larger and thicker crude oil is used to produce and enhance the characteristic of motor oil and some additives are used to increase specific motor oil characteristics. A hydrocarbon is the main portion of an typical motor oil that ranges from 18 to 34 C (carbon) particles for the individual atom. One of its most outstanding features is the motor oil viscosity, as it can support a lubricating film between the propelling sections. Viscosity is the fluid 's property to counter flux and can be said as the fluid 's thickness. The viscosity of motor oils should be so viscous that they are sufficiently viscous to hold lubricant films in the propelling parts and to run through any part. Changes in the viscosity of motor oil due to changes in temperature using the viscosity profile are determined. In order to create roads sustainably, as well as to replace bitumen in order to reduce the emissions generated by bitumen production. In order to address the above problems, alternative materials have been tested which can be used to cover bitumen partially on road pavement. Because of its lower viscus of waste motor oil, it is checked to prevent ageing, resulting in lower compactness and temperatures. Asphalt mixtures are also used. [12,16,] It is also environmentally friendly because waste motor oil can not be reused completely. The introduction of waste motor oil, however, has shown problems such as an increase in routing and poor elasticity recovery. [18,19,20]

- Test of soft spots according to IS 1205 1978;
- IS 1203 1978 penetration test
- IS 1208 1978 Ductility Test
- IS 1202 1978 Specific Gravity Test

III. RESULTS AND DISCUSSION

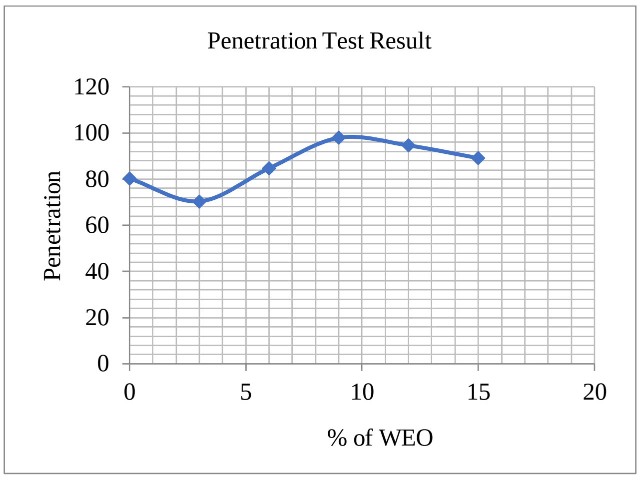
A. Penetration Test Of Bitumen With Waste Engine Oil

A comprehensive investigation was undertaken to evaluate the impact of waste engine oil (WEO) on a set of bitumen samples through a series of penetration tests. The samples analysed in this study consisted of waste engine oil, with varying percentages of inclusion. These percentages were specifically measured at 0%, 3%, 6%, 9%, 12%, and 15%. The experiments were carried out in strict adherence to the guidelines outlined in IS code 1203, aiming to guarantee the precision and dependability of the findings. In order to gain a comprehensive understanding of the behaviour of the modified bitumen, a series of multiple samples were meticulously prepared. The test results are shown in Table1.

Table 1: Penetration Test Result of Bitumen with Waste Engine Oil

% age WEO Powder	Penetration Test Result
0	80
3	70
6	85
9	98
12	95
15	89

The conducted penetration tests have revealed a discernible correlation between the existence of waste engine oil and the penetration characteristics of bitumen. The utilisation of waste engine oil (WEO) as a modifier in bitumen has been found to have an impact on its penetration properties. In comparison to the original VG10-grade bitumen, the incorporation of WEO results in a reduction in penetration. However, it has been observed that the introduction of WEO can actually enhance the penetration of bitumen up to a certain concentration. In this particular study, the optimal concentration of WEO for achieving enhanced penetration is determined to be 9%. Upon surpassing the aforementioned optimal threshold, subsequent increments in waste engine oil content exhibit a negative correlation with penetration values, leading to a decline in the latter. The aforementioned findings provide valuable insights regarding the development of modified bitumen compositions tailored for specific road construction applications, with a particular focus on the importance of penetration characteristics. The Penetration test result graph of bitumen with waste engine oil is shown in Figure. 1



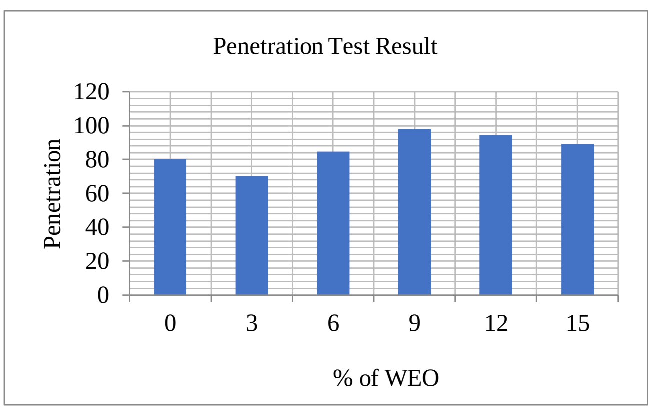


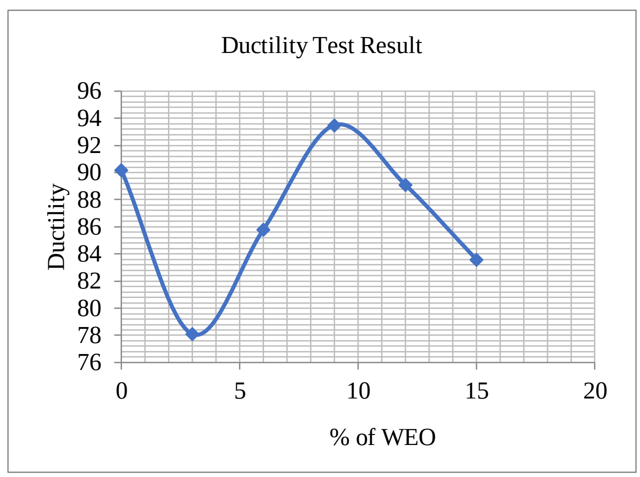
Figure 1: Penetration Test Result Graph of Bitumen with Waste Engine Oil

B. Ductility Test Of Bitumen With Waste Engine Oil

The objective of the ductility test, as outlined in the IS 1208 guidelines, was to evaluate the performance characteristics of bitumen samples containing different proportions of waste engine oil (WEO). The experimental conditions encompassed various proportions of waste engine oil, specifically 0%, 3%, 6%, 9%, 12%, and 15%, which were integrated into the bitumen samples. The findings derived from the conducted ductility test have provided valuable insights regarding the correlation between the presence of waste engine oil and the ductility characteristics of bitumen. The results obtained from the ductility test reveal several key findings that are of significant importance. These findings shed light on the behaviour and characteristics of the material under investigation. It is imperative to analyse and understand these findings in order to gain insights into the material's ability to deform plastically without fracturing. Firstly, the ductility test demonstrated that the material exhibits a notable degree of plastic deformation before failure. The findings of this study provide compelling evidence supporting a correlation between the inclusion of waste engine oil (WEO) and the improvement of ductility in bitumen. The test results are shown in Table. 2 and Ductility test result graph is shown in Figure 2.

Table 2: Ductility Test Result of Bitumen with Waste Engine Oil

% age WEO Powder	Ductility Test Result
0	90
3	78
6	86
9	94
12	89
15	84



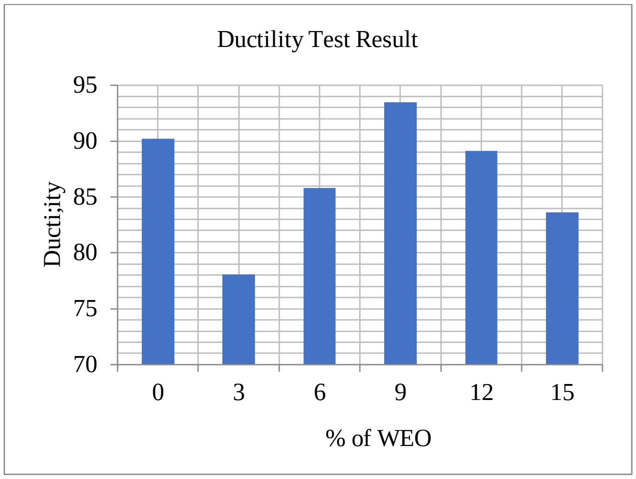


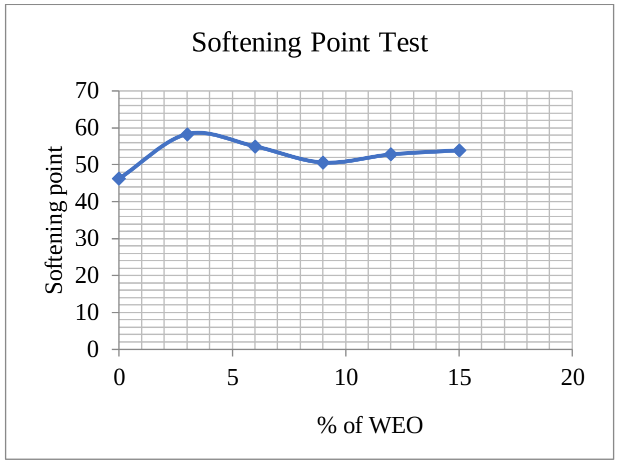
Figure 2: Ductility test result graph

C. *Softening Point Test Of Bitumen With Waste Engine Oil*

The softening point test was performed in accordance with the IS code IS-1205 to assess the bitumen samples. These samples were modified with different proportions of waste engine oil (WEO), ranging from 0% to 15% in increments of 3%. The findings derived from this experimental analysis reveal a discernible correlation between the softening point temperature and the concentration of WEO (Water Extractable Organic) compounds. At the baseline measurement of 0% waste engine oil (WEO) content, the softening point temperature was determined as the reference point. In the sample containing 3% waste engine oil (WEO), an increase in the softening point temperature was observed when compared to the sample without any WEO (0% WEO). This finding suggests that the addition of a small quantity of waste engine oil has a positive effect on the softening point. The test results are shown in Table. 3 and Softening point test result graph is shown in Figure 3.

Table 3: Softening Point Test Result of Bitumen with Waste Engine Oil

%age WEO Powder	Softening Point Test
0% WEO	42ºC
3% WEO	53 ºC
6% WEO	50 ºC
9% WEO	46 ºC
12% WEO	48 ºC
15% WEO	49 ºC



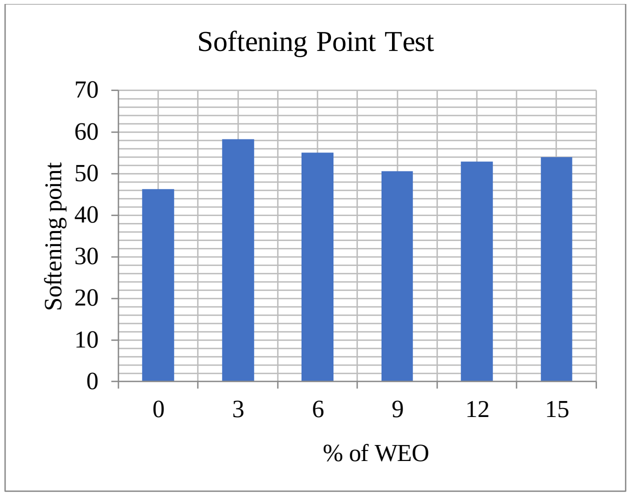


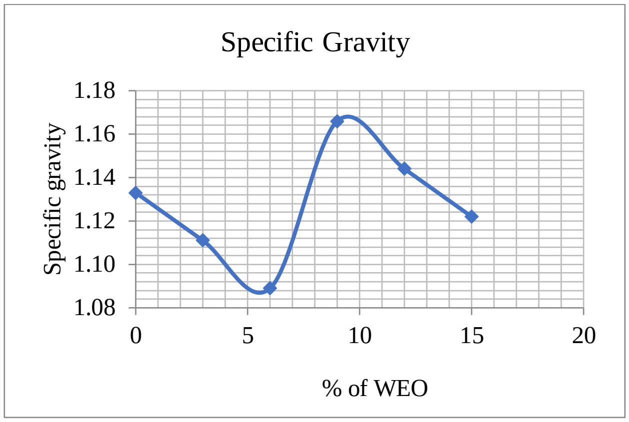
Figure 3: Softening Point Test Result Graph

D. *Specific Gravity Test Of Bitumen With Waste Engine Oil*

The investigation involved conducting a specific gravity test on multiple samples of bitumen that were subjected to varying proportions of waste engine oil (WEO). These proportions included 0%, 3%, 6%, 9%, 12%, and 15% of WEO. The results obtained from this experiment were intriguing and worthy of discussion. The test results are shown in table 4 and Specific gravity test result graph is shown in figure 4.

Table 4: Specific Gravity Test Result of Bitumen with Waste Engine Oil

% age WEO Powder	Specific Gravity
0	1.13
3	1.11
6	1.09
9	1.17
12	1.14
15	1.12



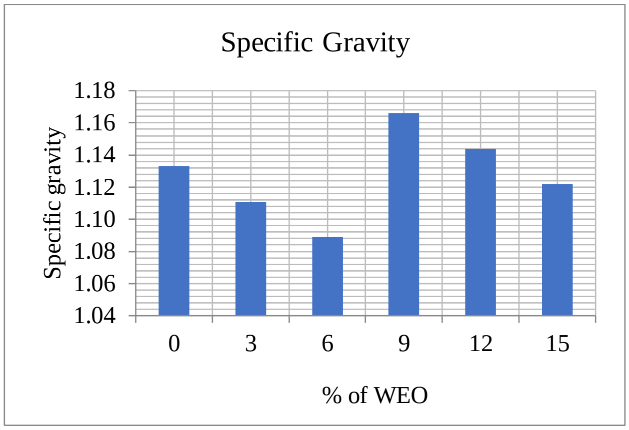


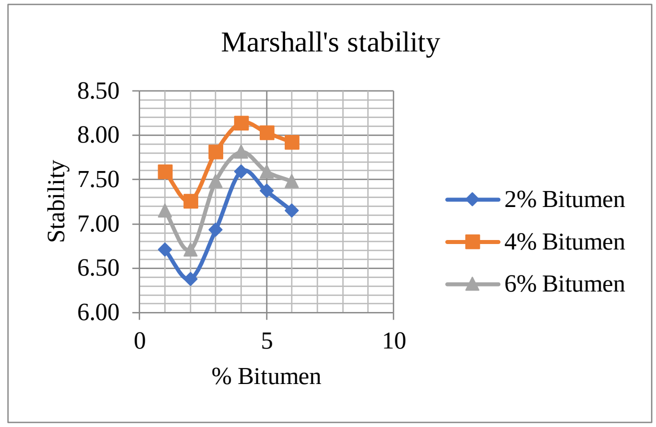
Figure 4: Specific Gravity Test Result Graph

E. Marshall Stability Test Of Bitumen With Waste Engine Oil

The present study involved the conduction of Marshall stability tests on a range of bitumen samples. Each sample was formulated with varying proportions of waste engine oil (WEO), specifically 0%, 3%, 6%, 9%, 12%, and 15%. The purpose of conducting these tests was to evaluate the stability of the modified bitumen mixtures and gain insights into the influence of the addition of WEO on their performance. The findings of this study indicate that the inclusion of waste engine oil (WEO) has a discernible impact on the stability of bitumen mixtures. In the course of our experimentation, it was determined that the composition consisting of 9% WEO and 4% bitumen content exhibited the greatest degree of stability when compared to all other compositions that were subjected to testing. The composition characterised by a 9% weight equivalent of oil (WEO) and a 4% bitumen content exhibited the highest level of stability, as determined through experimental analysis. The findings suggest that, among the various proportions examined, the bituminous mixture achieved the highest stability when composed of 9% waste engine oil and 4% bitumen content. The test results are shown in Table 5 and Marshall Stability test result graph is shown in Figure 5.

Table 5: Marshall Stability Test Result of Bitumen with Waste Engine Oil

WEO %	2% Bitumen	4% Bitumen	6% Bitumen
0	6.71	7.59	7.15
3	6.38	7.26	6.71
6	6.93	7.81	7.48
9	7.59	8.14	7.81
12	7.37	8.03	7.59
15	7.15	7.92	7.48



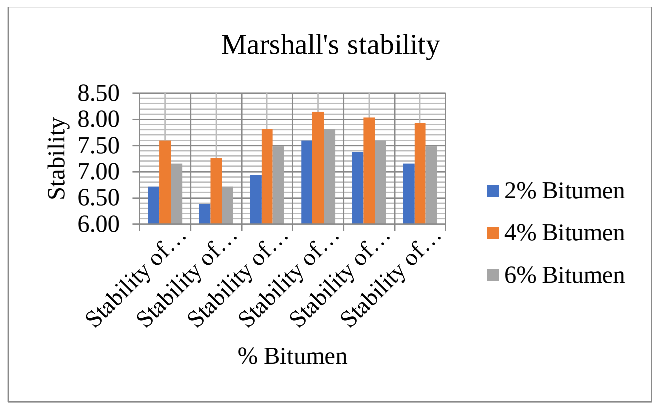


Figure 5: Marshall Stability Test Result Graph

The experimental results indicate that the optimal stability was observed when a mixture consisting of 9% waste engine oil and 4% bitumen content was utilised. The results of this study underscore the significance of meticulously optimising the ratios of waste engine oil and bitumen in order to attain the desired stability properties in bituminous mixtures intended for road construction and infrastructure applications.

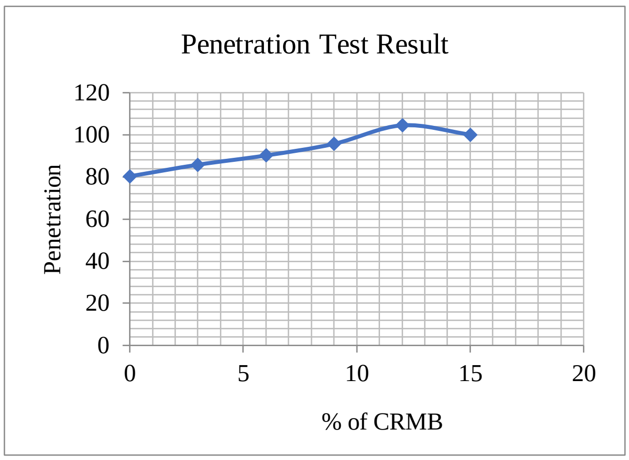
F. Penetration Test Of Bitumen With Waste CRMB

A series of penetration tests were performed on a range of bitumen samples, each containing varying proportions of waste CRMB (Crumb Rubber Modified Bitumen). The samples were prepared to include concentrations of 0%, 3%, 6%, 9%, 12%, and 15% of CRMB. The tests conducted in this study were performed in strict adherence to the guidelines outlined in IS code 1203. The primary objective of these tests was to evaluate the penetration characteristics of the modified bitumen. The findings of this study suggest that the inclusion of waste crumb rubber modified bitumen (CRMB) leads to an increase in the penetration value of

VG10-grade bitumen. This observation suggests that this particular sample possessed enhanced workability and a decreased resistance to penetration. The findings of this study reveal an intriguing trend in the relationship between waste CRMB content and penetration value. Specifically, it was observed that as the waste CRMB content was increased beyond the threshold of 12%, a decrease in penetration value was observed. The test results are shown in table 6 and Penetration test result graph is shown in figure 6.

Table 6: Penetration Test Result of Bitumen with Waste CRMB

% age CRMB Powder	Penetration Test Result
0	80
3	86
6	90
9	96
12	105



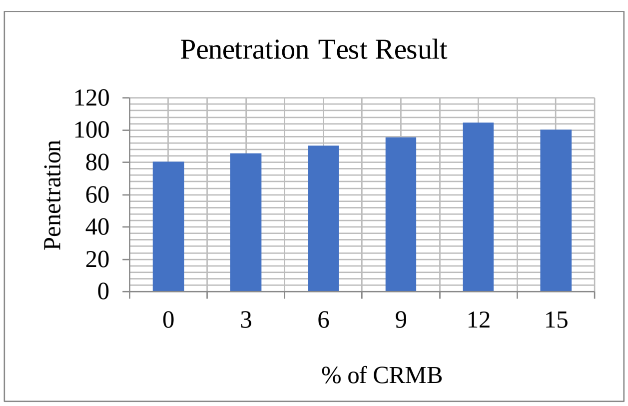


Figure 6: Penetration Test Result Graph of Bitumen with Waste CRMB

At a concentration of 15% CRMB, the penetration value exhibited a decrease to 91 mm, suggesting a decline in workability and an elevation in penetration resistance when compared to the composition containing 12% CRMB. The findings of the conducted penetration test reveal the discernible impact of waste crumb rubber modified bitumen (CRMB) on the penetration properties of bitumen. The experimental results indicate that the optimal waste CRMB content for achieving the highest penetration is 12%. This finding suggests that incorporating 12% waste CRMB into the mixture enhances the workability of the material. Subsequently, the augmentation of the CRMB (Crumb Rubber Modified Bitumen) content to a level of 15% resulted in a notable decline in penetration, thereby suggesting a discernible decrease in workability. The aforementioned findings underscore the significance of meticulously determining the appropriate ratio of waste crumb rubber modified bitumen (CRMB) in order to attain the desired penetration properties in modified bitumen used for road construction and infrastructure applications.

G. Ductility Test Of Bitumen With Waste CRMB

Ductility tests were performed on a series of bitumen samples that encompassed a range of waste CRMB (Crumb Rubber Modified Bitumen) concentrations. The concentrations investigated included 0%, 3%, 6%, 9%, 12%, and 15%. The tests conducted in this study adhered to the protocols specified in IS 1208 in order to assess the ductility properties of the modified bitumen. The findings of this study indicate that the incorporation of waste crumb rubber modified bitumen (CRMB) has a positive impact on the ductility of bitumen. The utilisation of waste crumb rubber modified bitumen (CRMB) results in an observable improvement in the ductility properties of the bituminous material. The investigation revealed a significant enhancement in ductility when incorporating waste crumb rubber modified bitumen (CRMB) up to a concentration of 12%. The test results are shown in table 7 and Ductility test result graph is shown in figure 7.

Table 7: Ductility Test Result of Bitumen with Waste CRMB

% age CRMB Powder	Ductility Test Result
0	90
3	68
6	75
9	83
12	97
15	92

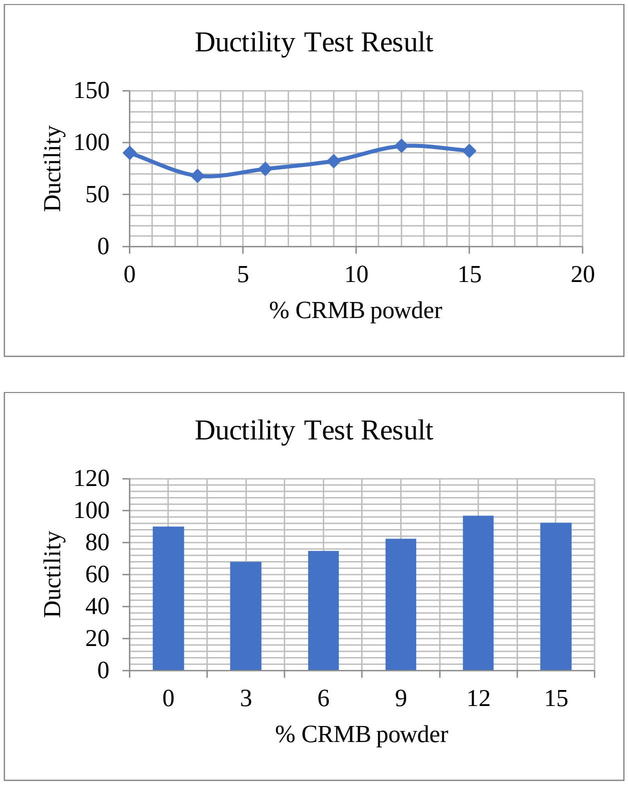


Figure 7: Ductility test result graph of bitumen with waste CRMB

The experimental results demonstrate that the bitumen composition containing 12% crumb rubber modified bitumen (CRMB) content displayed the most notable level of ductility. This finding implies that the bitumen mixture with this specific CRMB content possesses enhanced flexibility and elongation properties. The findings obtained from the conducted ductility tests provide empirical evidence that waste crumb rubber modified bitumen (CRMB) can indeed significantly improve the ductility properties of bitumen. The experimental findings indicate that the highest level of ductility was achieved when the content of CRMB (Crumb Rubber Modified Bitumen) reached 12%. Subsequent increases in CRMB content did not yield any additional enhancements in ductility. The results of this study highlight the considerable potential of waste crumb rubber modified bitumen (CRMB) as a valuable additive for improving the ductility and flexibility of bituminous materials. This enhancement has significant advantages for a wide range of applications in the field of road construction and infrastructure development.

H. Softening Point Test Of Bitumen With Waste CRMB Powder

The experimental investigation involved the performance of the softening point test on bitumen specimens containing different proportions of waste CRMB (Crumb Rubber Modified Bitumen), namely 0%, 3%, 6%, 9%, 12%, and 15%. The test procedure was conducted in accordance with the guidelines outlined in the IS code IS-1205. The observed data suggests that the incorporation of waste crumb rubber modified bitumen (CRMB) leads to fluctuations in the softening point of bitumen. In the preliminary stages of experimentation, it was observed that with the gradual incorporation of CRMB (Crumb Rubber Modified Bitumen) into the mixture, ranging from 0% to 3%, there was a discernible rise in the softening point temperature. The test results are shown in table 8 and Softening point test result graph is shown in figure 8.

Table 8: Softening Point Test Result of Bitumen with Waste CRMB Powder

% age CRMB Powder	Softening Point Test
0	46
3	62
6	57
9	54
12	50
15	53

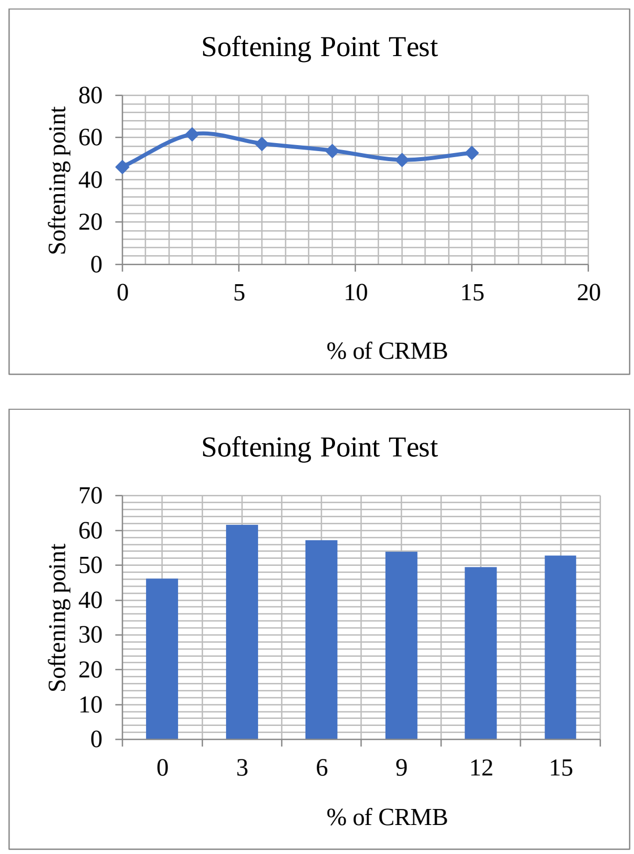


Figure 8: Softening Point Test Result Graph of Bitumen with Waste CRMB Powder

This notable trend indicates a potential enhancement in the material's ability to withstand higher temperatures, thereby implying an improvement in its thermal resistance properties. The most salient observation was recorded when the bitumen composition incorporated a 12% concentration of waste crumb rubber modified bitumen (CRMB). At this juncture, it has been determined that the temperature at which the softening point occurs has reached its minimum value. The findings of this study suggest that the bitumen containing 12% CRMB content exhibited the most notable resistance to softening caused by temperature variations. Following the increment of the crumb rubber modified bitumen (CRMB) content to 15%, a notable elevation in the softening point temperature was observed. The findings of this study indicate that the incorporation of more than 12% crumb rubber modified bitumen (CRMB) may result in a marginal reduction in the material's resistance to thermal softening. The findings derived from the softening point test provide valuable insights into the influence of waste crumb rubber modified bitumen (CRMB) on the thermal characteristics of bituminous materials. The bitumen composition containing 12% CRMB content exhibited superior resistance to thermal softening, indicating an optimal threshold for this specific modifier. The aforementioned findings offer significant insights into the feasibility of employing waste CRMB (Crumb Rubber Modified Bitumen) as a means to improve the thermal stability of bitumen. This is particularly important in the context of road construction, where the materials used must withstand diverse temperature conditions.

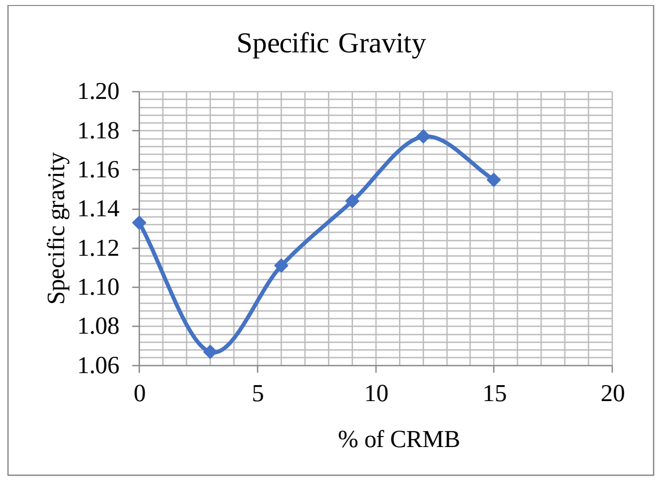
I. *Specific Gravity Test Of Bitumen With Waste CRMB Powder*

The experiment involved the performance of a specific gravity test on bitumen specimens that were supplemented with different proportions of waste CRMB, specifically 0%, 3%, 6%, 9%, 12%, and 15%. The test results are shown in Table. 9 and Specific gravity test result graph is shown in Figure 9.

Table 9: Specific Gravity Test Result of Bitumen with CRMB Powder

%age CRMB Powder	Specific Gravity
0	1.13
3	1.07
6	1.11
9	1.14
12	1.18
15	1.16

The objective of this experiment was to ascertain the specific gravity of each sample. The observed specific gravity values of the bitumen samples demonstrated a consistent pattern in response to varying proportions of waste crumb rubber modified bitumen (CRMB). The introduction of CRMB resulted in a notable decrease in specific gravity, suggesting a concurrent decrease in the density of the modified bitumen. The primary finding of this study pertains to the optimal specific gravity achieved at a waste crumb rubber modified bitumen (CRMB) content of 12%. The data suggests the presence of an ideal threshold at which the bitumen demonstrates its maximum density and minimal volume for a given mass. The specific gravity values exhibited a decrease when the percentage of CRMB was raised beyond the threshold of 12%. The findings of this study indicate that the incorporation of more than 12% crumb rubber modified bitumen (CRMB) may result in a notable reduction in the density of the modified bitumen.



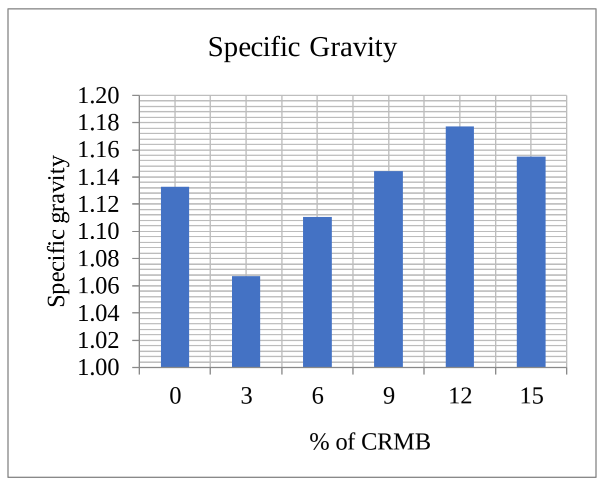


Figure 9: Specific Gravity Test Result of Bitumen with CRMB Powder

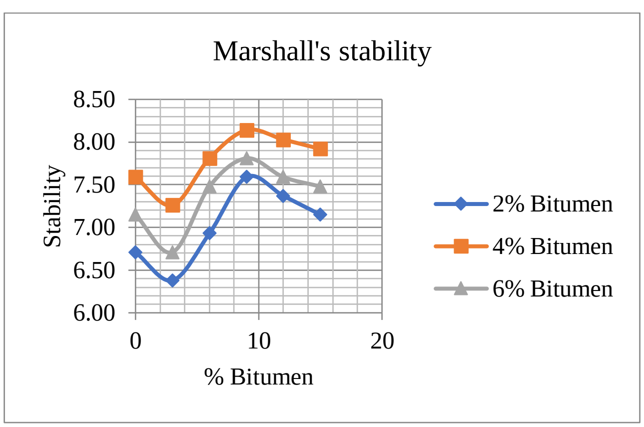
The robustness of the specific gravity test is underscored by the consistent outcomes observed across various sample sizes and bottles. The experimental results indicate that the utilisation of 12% waste crumb rubber modified bitumen (CRMB) resulted in the highest specific gravity. This observation suggests that this particular percentage of waste CRMB led to the maximum density achieved in the bitumen composition. Upon surpassing this threshold, a discernible decline in specific gravity was observed, indicating a plausible attenuation of bitumen density. The aforementioned findings offer significant insights into the influence of waste crumb rubber modified bitumen (CRMB) on the density and volume properties of bitumen. These properties play a crucial role in the field of road construction and have a direct impact on the performance of pavements.

J. Marshall Stability Test Result Of Bitumen With Waste CRMB Powder

The present study involved conducting the Marshall stability test on bitumen specimens that were modified with varying proportions of waste CRMB powder. The experimental investigation encompassed six different sample compositions, each characterised by a distinct CRMB content. These compositions included bitumen specimens with 0%, 3%, 6%, 9%, 12%, and 15% CRMB content. The observed Marshall stability values exhibited a discernible pattern as the proportion of waste CRMB (Crumb Rubber Modified Bitumen) was manipulated. The experimental findings revealed that the bitumen blend with a 12% crumb rubber modified bitumen (CRMB) content, in conjunction with a 4% bitumen content, exhibited the maximum stability value. The experimental findings suggest that a specific combination of components led to an ideal mixture, yielding the greatest level of stability compared to other compositions examined in the study. The test results are shown in table 10 and Marshall stability test result graph is shown in figure.

Table 10: Marshall Stability Test Result of Bitumen with CRMB

CRMB %	2% Bitumen	4% Bitumen	6% Bitumen
0	6.71	7.59	7.15
3	6.38	7.26	6.71
6	6.93	7.81	7.48
9	7.59	8.14	7.81
12	7.37	8.03	7.59
15	7.15	7.92	7.48



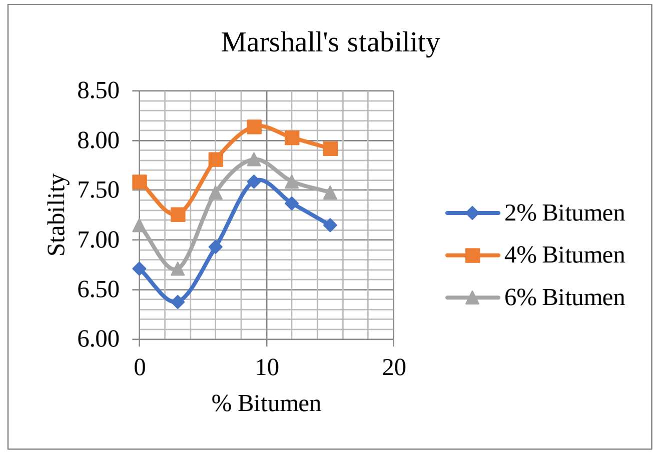


Figure 10: Marshall Stability Test Result Graph

A notable observation was made regarding the stability values as the bitumen content was modified. Specifically, it was observed that there was a decrease in stability at both the 2% and 6% bitumen content levels. The stability values exhibited a decrease when comparing the compositions with 2% and 6% bitumen content to the composition containing 4% bitumen content.

The aforementioned findings highlight the significance of the proportion of CRMB (Crumb Rubber Modified Bitumen) and bitumen content in exerting an influence on the Marshall stability of the bitumen mixture. The experimental results indicate that the incorporation of 12% CRMB (Crumb Rubber Modified Bitumen) in conjunction with a 4% bitumen content resulted in the highest stability. This finding suggests that this particular combination could be considered as an optimal approach for improving the stability of bitumen in road construction. The observed decline in stability at bitumen content levels of 2% and 6% highlights the importance of carefully selecting suitable proportions in order to attain the desired performance characteristics in bituminous mixtures. The findings presented in this study offer significant contributions towards enhancing the road pavement performance through the optimisation of CRMB-modified bitumen composition.

IV. CONCLUSION

The extensive array of tests and inquiries carried out on bitumen that has been modified with waste engine oil (WEO) and crumb rubber modified bitumen (CRMB) has provided significant knowledge regarding the characteristics and effectiveness of these modified bituminous mixtures. The implications of these findings are of great importance for the field of road construction and infrastructure development. The following are the main findings derived from this study:

A. Modification by Waste Engine Oil (WEO)

- The addition of Waste Engine Oil (WEO) to bitumen resulted in a notable and consistent enhancement in ductility. The ductility of bitumen was observed to enhance with an increase in the percentage of waste engine oil (WEO), ultimately attaining an optimal value at 9% WEO. The observed increase in ductility indicates enhanced flexibility and resistance to cracking in bituminous materials.

- Penetration: The results of the conducted penetration tests indicated a decrease in the penetration value upon the introduction of WEO. Nevertheless, there was a notable enhancement in penetration when incorporating a maximum of 9% weight equivalent of oil (WEO), suggesting an amelioration in workability without an excessive degree of softening.
- The softening point of bitumen demonstrated a significant rise at a concentration of 3% WEO, followed by a gradual decline until reaching an optimal concentration of 9% WEO. At this juncture, there was an observed elevation in the softening point, indicating the existence of an optimal range that enhances temperature susceptibility.
- The addition of waste engine oil (WEO) resulted in a decrease in the specific gravity of bitumen. The highest specific gravity was recorded at a WEO content of 9%. This finding suggests that a WEO concentration of 9% achieves an ideal equilibrium between density and workability.
- The results of the Marshall stability tests indicated that the highest stability value was attained when the mixture contained 9% WEO and 4% bitumen content. The stability exhibited a decrease at bitumen content levels of both 2% and 6%, thereby underscoring the significance of bitumen content in attaining optimal stability.

B. Modification of bitumen with crumb rubber powder (CRMB

- Penetration tests were conducted to evaluate the impact of CRMB addition on the penetration of VG10-degree bitumen. The results demonstrated that the penetration of VG10-degree bitumen exhibited an increase as the percentage of CRMB was increased, with the highest penetration value observed at a CRMB content of 12%. Nevertheless, the penetration values exhibited a decline as the content of CRMB surpassed the threshold of 12%.
- The results of the ductility tests demonstrated a notable enhancement in ductility when incorporating CRMB, particularly when the CRMB content reached 12%.
- The softening point of bitumen exhibited an upward trend upon the incorporation of CRMB, reaching a peak at a 12% concentration, followed by a marginal decrease. This observation suggests the existence of an optimal range for enhancing temperature resistance.
- The addition of CRMB content resulted in a decrease in specific gravity. The highest specific gravity was observed at a CRMB content of 12%, indicating an optimal trade-off between density and workability.
- The maximum stability value was observed to occur when the mixture contained 12% CRMB and 4% bitumen content, as determined by the Marshall Stability test. The stability of the mixture was observed to decrease at both 2% and 6% bitumen content, highlighting the significant impact of bitumen content on stability.

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