EXPERIMENTAL INVESTIGATION ON EFFECT OF CRUMB RUBBER IN BITUMINOUS MIXTURES FOR CONSTRUCTION OF FLEXIBLE PAVEMENTS.

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Abstract

This study examines the impact of adding waste tires in the form of crumbs as an additive in a bituminous mix. In order to understand the behavior of the bituminous mixtures due to incorporation of crumb rubber (CR) and effect on the properties of bitumen binder, different experimental investigations were carried out on virgin bitumen followed by that on the crumb rubber modified bitumen (CRMB). For the comparative analysis, four different percentages of crumb rubber (5%, 8%, 10%, and 12%) by the weight of bitumen were used. The experiments conducted revealed that with the increase in CR percentage (0% to 12%) in the bituminous mix, the penetration and ductility of CRMB decreased. Similarly the softening point and flash and fire point increased with increase in CR percentage within the mix. The findings of the penetration test and softening point test were used for calculating the CR modified bitumen mixture's temperature susceptibility as a measurement of their penetration index (PI). Also the comparisons with existing studies were carried out and inferences were drawn. From this study it is concluded that using CRMB has far more benefits over the conventional bitumen and enhance the overall strength and efficiency of the asphalt mixture used for construction of pavements. Utilizing this recovered CR also offers a secure method of getting rid of such non-biodegradable pollutants.

Keywords: Asphalt, Crumb Rubber, Flexible Pavement, Modified Bitumen, Sustainability

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1. INTRODUCTION

In an effort to improve the characteristics and productivity of asphalt mix while minimizing asphalt damage, there have been many research efforts to find more effective methods to utilize wastes like crumb rubber (CR) as a modifier. Scrap rubber disposal has grown to be a significant issue in modern times. These materials pollute the environment because they are a biological, throwaway product. Used tires can be crushed and recycled to create crumb rubber [1]. In many developing nations, rubber waste byproducts have recently attracted a lot of interest for use in building roads. These materials are chosen for road building based on technical, financial, and ecological factors, and the results are positive [2]. India produces millions of tonnes of rubber trash each year. By incorporating such elements in the making of highway roads, problems related to environmental damage and disposal can be effectively solved [3].

Given the prevalence of such pollutants in India, analysis of such pollutants was deemed necessary to create guidelines for their increased usage in the construction of roads where larger financial returns may be achievable. Since it involves the recycling of waste materials, using CR for strengthening asphalt road surfaces has become a wise strategy for long term rational growth. For the sake of improving the efficiency of hot-mix asphalt (HMA), CR can also be utilized as a substitute polymer product [4].

Tire debris is recycled to create the CR utilized in crumb rubber modified bitumen pavement. Previous studies have identified the parameters that contribute towards formation of CRMB mixtures that perform with more superiority at higher as well as lower temperature conditions. Such aspects include CR particle size, particle features, the process that transpires during the mixing process or fusion process, CR vulcanization and disintegration, and CR qualities and kind [5].

Using CR can help reduce the amount of energy consumed to produce modifiers, the amount of waste emissions produced, and the amount of landfill space needed to store leftover tires. When compared to traditional pavement, CRMB pavement can reduce vehicle noise by 40% to 88% [6]. To increase their resilience to persistent distortion (rutting) and cracking, the qualities of traditional asphalt mix must be increased. Via modifications using the right ingredients, the mechanical qualities of traditional asphalt mixture can be enhanced [7]. With aim to increase pavement resistivity while subjected to fluctuating temperatures, some prior study examined the viability of employing several varieties of synthetic polymers [8]. The functionality of bitumen mix (BM) may be optimized by modifying binders using natural or synthetic ingredients, such as CR [9]. The anti-aging, anti-fatigue, limited temperature anti-cracking, high thermal stability, and moisture stability of CR are just a few of its advantageous traits [10, 11].

In every region of our nation (India), these materials ought to be employed while building roads. Waste tires can be used as aggregate after being cut to the right size and being mixed with different types of bitumen. This decreases the dependence on depleting organic aggregates and lessens the pollution caused by used tires, both of which contribute to a reduction in global warming and health issues [12].

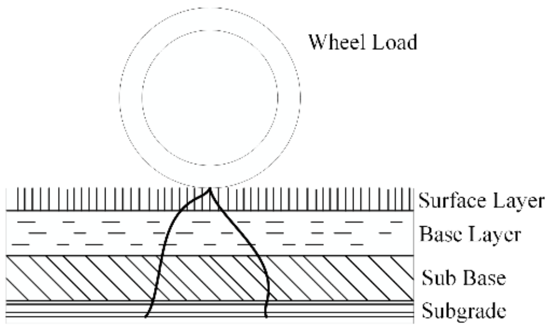

Figure 1: Different layers of flexible pavements

2. MATERIALS

1. Virgin bitumen.
2. Crumb rubber mixed with bitumen in different proportions.

1. **Virgin Bitumen:** Petroleum comes in the form of bitumen, which is a thick, dark, gooey, and extremely viscous liquid or semi-solid. In the construction sector, it is most frequently used as a binding material for asphalt concrete as well as bituminous surface treatments. Bitumen is an intricate mixture of hydrogen and carbon compounds made up by aromatic compounds, resins, and asphaltenes that is manufactured by distilling crude oil [13]. It is distinguished by its high melting point, moderate volatility, and significant viscosity.

   A variety of factors including its origin and processing procedures, bitumen can have a wide range of compositions and characteristics. Bitumen grade used in this study is bitumen

60/70. This bitumen grade is currently being used for the paving of national as well as state highways in India.

2. **Crumb Rubber:** Used tires or other rubber goods are ground into tiny, fine fragments to create crumb rubber, a type of recycled rubber material. The finished product is subsequently put to use in a number of projects, including the construction of roads, playgrounds, and sports fields [14]. Without a doubt, the growing heaps of used tires raise ecological problems. The ultimate purpose associated with this study aims to discover ways to eliminate crumb rubber by incorporating it into Portland cement concrete while making a final product with superior engineering characteristics. CR used in this study had a specific gravity of 1.16 and was unadulterated by metal, cloth, and other impurities. The factors listed in table 1 should be taken into account when combining waste such as CR in pavement construction.

(a) (b)

Figure 2: (a) Bitumen (b) Crumb Rubber

Table 1: Factors affecting pavement construction

Factors	Details
Type of pavement	It is important to identify the type of pavement to be constructed before using CR in a mix because different type of roads will require different type and quantity of CR.
Strength of pavement	Pavement made of waste such as CR should have structural strength not less than the strength of traditional pavement.
Performance of CR	CR must perform up to the standards and should not hinder with the overall performance of the bitumen [11].
Initial capital	Cost of collection, handling and transportation of CR must be taken into the account.
Durability	CR must be durable enough to give the optimum efficiency and maximum output. [15]
Safety	Safety must be considered at every stage of the construction process. Health of pavement workers must be considered as well [4].

Today's increased traffic and weather patterns along with diminishing of natural aggregate resources may contribute to the serious pavement issues. The qualities of the pavement must therefore be improved by considering alternate sources. By altering the qualities of bitumen, we may satisfy the requirements for strength, ecological sustainability, and the economy [16, 17].

To meet the demands of the moment, it can be altered by adding various additives to it, such as CR. In depth analysis of previous research work was conducted to explore their findings and the overall progress being made over the past few years. The summary of these studies is given in table 2. The overall goal of conducting the research work is utilizing CR in BM and to alter the characteristics of the mix so that the modified mix obtained shows better qualities over the conventional mix and could be used more efficiently.

Along with this it is also crucial to figure out the ideal CR dosage for mixing purpose. The CR quantity to be added in the mix must ensure that the mix has adequate strength to withstand heavy loads and should have enough durability. Also disposal of crumb rubber in an economic way is one of the objectives of the study.

Table 2: Summary of literature studies on use of crumb rubber in bitumen mix for flexible pavements

Paper	Findings
[29]	BM with certain CR% added to it had better durability and was more efficient.
[30]	Combination of waste plastic and discarded rubber make bitumen mix efficient and durable.
[31]	Adding CR in asphalt mix may increase pavement's resilience to rutting and increase its endurance.
[32]	Bitumen's physical characteristics altered when CR was added as a modifier.
[33]	Stability at Elevated temperatures and ductility of CRMB had both improved.
[34]	Specimens in which rubber is used as fine aggregate show superior properties than specimens in which rubber is used as coarse aggregates.
[35]	Using crumb rubber in BM helps in preventing ecological degradation and promotes global environmental sustainability.
[36]	Reduction in overall thickness of the surface course as well as duration of maintenance is a possibility in CRMB pavements.
[37]	The mixture's rigidity and resilience increased with inclusion of crumb rubber to it.
[38]	The maximal force at which modified bitumen breaks at lower temperatures is greatly increased by CR with force ranging from 40% to 100% compared to pure bitumen.
[39]	During building and maintenance stages, the energy spent by rubberized bitumen mix was often less compared to that of conventional bitumen mix.
[40]	Using CR in asphalt mix results in less bitumen usage, no hazardous emissions and higher resistance to rutting.
[41]	Incorporating CR in a bitumen mix helps in avoiding the employing of anti-stripping chemicals.
[42]	Tensile strength ratio of BM was greatly enhanced by including CR, making them less susceptible to moisture related damage.

3. RESEARCH METHODOLOGY AND MATERIALS

Utilizing discarded rubber in crumb form in a bitumen mix is the primary focus of this investigation. The required materials for carrying out this investigation are crumb rubber, and bitumen (60/70). To create a uniform bitumen mixture, the rubber is shred into tiny bits, mixed with bitumen while heating the mix simultaneously. In this study, the wet process of mixing was used. It was important to ascertain how the amended bitumen's tested qualities had changed. Experiments were performed on pure bitumen before being repeated on modified bitumen samples that contained 5%, 8%, 10% and 12% crumb rubber. Then, these altered features were contrasted with the properties of virgin bitumen and conclusions were drawn.

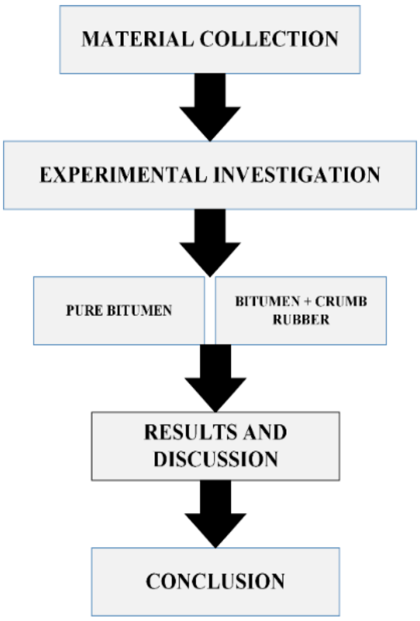

Figure 3: Flow Chart of Research Methodology

- **Testing on Bitumen**

The bitumen for the experimentation was brought from Basti Adda Chowk, Near Fish Market, G.T Road, Jalandhar City-144001. The examination of the bitumen samples was done using traditional bitumen tests. The tests in question were carried out in accordance with IS code guidelines; table below lists the pertinent codes.

Table 3: Tests conducted on bitumen with IS codes

S. No.	Test	IS code
1.	Penetration test	IS 1203:1978
2.	Softening point test	IS 1205:1978
3.	Ductility	IS 1208:1978
4.	Flash and fire point test	IS 1209:1978
5.	Specific gravity test	IS 1202:1978

- **Testing on crumb rubber**

The study's crumb rubber was acquired from the RS Rubber Mills in New Hardyal Nagar on Hoshiarpur Road in Jalandhar, 144001. The crumb rubber passing through the sieve of 4.75mm was utilized for conducting the tests on CR. Tests initially conducted on virgin bitumen were repeated on CRMB with 5%, 8%, 10% and 12% CR.

4. EXPERIMENTAL INVESTIGATION

a) **Penetration test:** The penetration test calculates the number of millimeters (mm) a stacked conventional needle will pierce into the bitumen specimen in five seconds within the given stress and temperature conditions. For this test, the temperatures and loading conditions are both constant. Temperature while testing was performed was kept at 25℃. The primary goal of conducting this experiment is to evaluate the bitumen's stability and, consequently, its capacity to withstand failure due to ruts and cracking distortion [18]. On prepared specimen, the penetration experiment was carried out to measure its hardness or consistency. The test was first carried out on virgin bitumen samples followed by CRMB samples. According to the data obtained from the test conducted as shown below, it is clear that the highest penetration value is for the virgin bitumen i.e. bitumen with 0% CR meaning the virgin bitumen has the least consistency. But as soon as CR is added to the bitumen mix, the penetration values start to decrease indicating that the bitumen has become more stiff or hard.

Figure 4: Penetrometer

More the quantity of CR added in the test, less is the penetration and hence more is the hardness or consistency of the bitumen sample. This indicates that adding CR to the BM helps the bitumen to become harder and hence increase its strength. Reduced penetration also means that the uniformity and flow resistance of the sample had improved, the rigidity of CRMB Specimen, and the resistance to rutting also increased. From the graph, it is clear that the least penetration value was obtained for 12% CRMB. Therefore we can say that the flexible pavements which are subjected to heavy traffic loads should have some quantity of CR added to it so as to increase its hardness and hence so the pavement can bear more loads without much deformations. The experiment's findings have been presented in table 4 and figure 5.

Table 4: Results Obtained for Penetration test

CRMB %	Reading	Trial			Mean value In mm
		Sample 1	Sample 2	Sample 3	
0%	Initial	190	254	323	**69**
	Final	254	323	397	
Penetration Values		**64**	**69**	**74**	
5%	Initial	0	0	0	**60**
	final	62	60	58	
Penetration Values		**62**	**60**	**58**	
8%	Initial	0	0	0	**48.666**
	Final	48	46	52	
Penetration values		**48**	**46**	**52**	
10%	Initial	0	0	0	**41**
	Final	40	39	44	
Penetration Values		**40**	**39**	**44**	
12%	Initial	0	0	0	**33**
	Final	34	30	34	
Penetration Values		**34**	**31**	**34**	

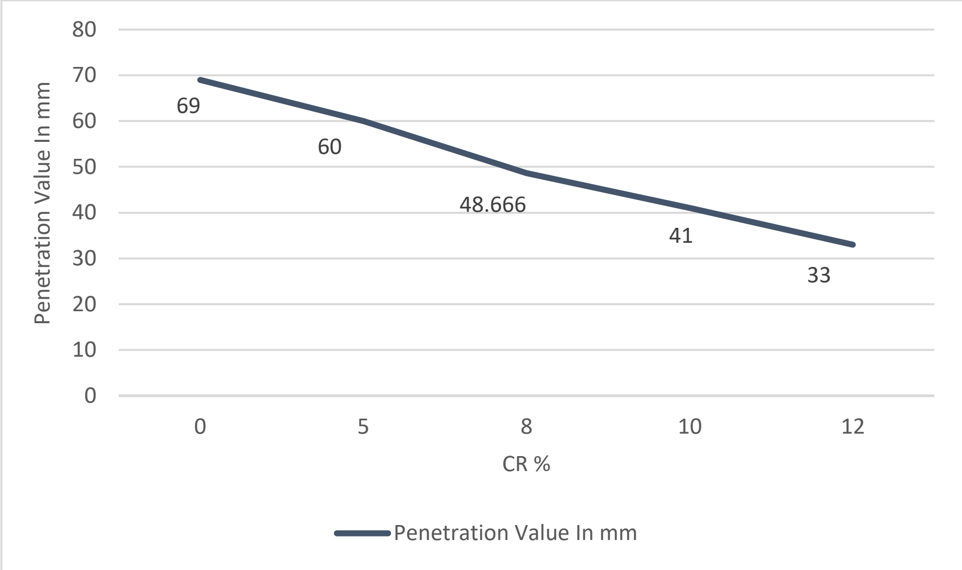

Figure 5: Penetration test result

b) Softening Point test: Softening point, as defined by IS: 334-1982, is the temperature when a ball with specified measurements passes through a bitumen specimen in a form and falls 2.5 cm in height. This bitumen test has been conducted using the Ring and Ball device [19]. With the use of this test, it is possible to predict the temperature at which the asphalt gets too loose to function well as a pavement material. From the test conducted it is clear that 0% CRMB has the lowest softening point, indication that it is the most soft mix sample among others and hence is more susceptible to become too soft when the temperature increases. Therefore 0% CRMB will lose its strength more easily and quickly. But when crumb rubber is added to the BM in certain proportions (5%, 8%, 10%, and 12%) the softening point of the mix increases and is highest for 12% CR. This indicates that with the addition of CR to the mix, at greater temperatures, bitumen will continue to be stable and will not lose its strength. Such mixes are thermally more stable and resistant to asphalt distortion. Hence adding CR to the bitumen mix is essential practice to be carried out especially in the regions where temperatures soar very high. According to the results shown in table 5, CRMB containing a greater percentage of CR might be utilized at elevated temperatures because due to the rise in CR%, the softening point of CRMB rises, as a result, the penetration level will go down. The amount of free radicals in CRMB was decreased because CR consumed the bitumen's lightweight oily elements. The anti-oxidative properties of CRMB was increased by the antioxidant and anti-ozone agent within CR. Such two aspects substantially enhance the anti-oxidative capability of the modified bitumen, resulting in an elevated softening point [21, 22].

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(a)

(b)

Figure 6: (a) Ring and ball apparatus set on heater (b) Ball touching the base upon heating

Table 5: Results obtained for softening point test

	CRMB%	Ball 1 (℃)	Ball 2 (℃)	Mean Value (℃)
Temperature at which the ball touches the bottom	0%	48	49	48.5
	5%	51	52	51.5
	8%	53	54	53.5
	10%	58	57.5	57.7
	12%	64	63	63.5

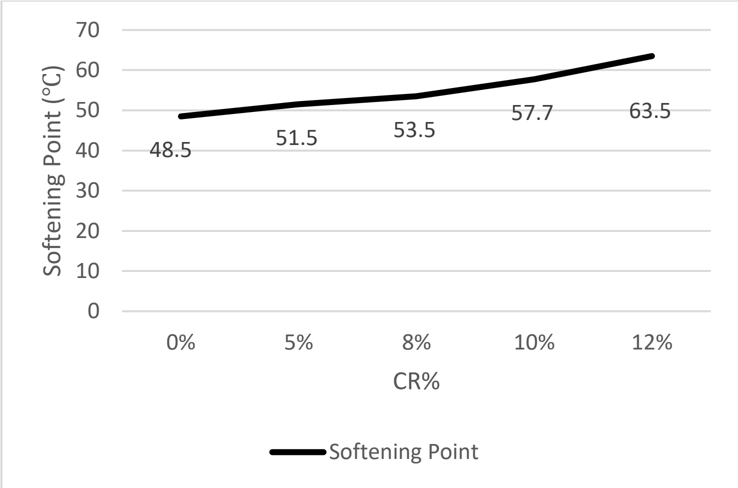

Figure 7: Softening point test result

Considering the standards mentioned in table 6, minimum value of softening point must be 57.2℃ and minimum and maximum penetration as 25mm and 75mm respectively, therefore both 10% as well as 12% CR can be used. However in regions where temperatures soar, 12 % CR should be preferred.

Table 6: Comparison of standard test values for CRMB with max and min values mentioned in ASTM D6114.

Test	Standard value		Test findings			
	Upper limit	Lower limit	5%	8%	10%	12%
Penetration (mm)	75	25	60	48.6	41	33
Softening point (℃)		57.2	51.5	53.5	57.7	63.5

After subjecting pure and CRMB to penetration test and softening point test, the findings from these tests were used for calculating the CRMB mixture's temperature susceptibility as a measurement of their penetration index (PI). The consistency factor changes depending on conditions of temperature, which is defined as temperature susceptibility. The equation (1) is used to calculate PI [23]. The comparison of PI depending on CR percentage is given in table 7.

$$PI = \frac{1952-500*\log(Pen_{25})-20*SP}{50*\log(Pen_{25})-SP-120} \quad \ldots\ldots (1)$$

Table 7: Comparison of PI between pure and modified bitumen samples

Virgin bitumen		CR %			
		5%	8%	10%	12%
Penetration (mm)	69	60	48.66	41	33
Softening point (℃)	48.5	51.5	53.5	57.7	63.5
PI	-0.817	-0.398	-0.430	0.086	0.718

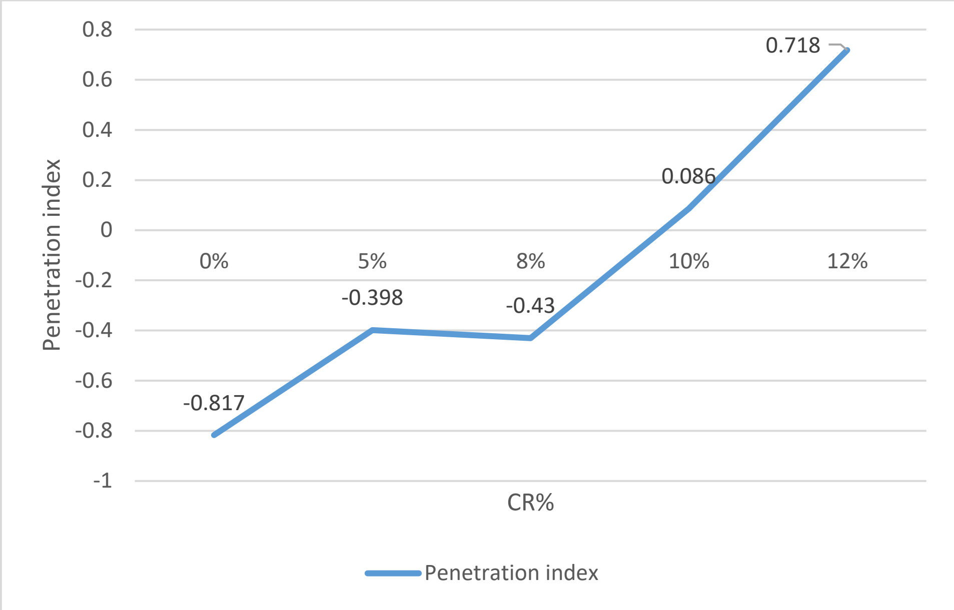

Figure 8: Variation in PI with CR%

From the figure 8 it can be seen clearly that pure bitumen (CR 0%) has the lowest PI whereas CRMB with 12% rubber additive has the highest PI. This suggests the bitumen mix's temperature susceptibility reduces by adding crumb rubber. Low pi values highlight that the mix is highly sensitive to temperature whereas the bitumen mix with greater PI is more resistant to permanent deformation and cracking at lower temperature [24]. As seen in the graph, CRMB with CR% as 10% and 12% have higher PI values and therefore show greater resistance to temperature susceptibility. Hence such CRMB samples should be considered for construction of flexible pavements.

c) Ductility Test: The length in centimeters that a normal bitumen briquette sample will extend prior to breaking whilst pulled away at a specific speed and temperature is a measure of bitumen's ductility [20]. The main insight provided by a bitumen sample's ductility is its tensile strength. Inadequate ductility can lead to cracking of bitumen. The temperature while conducting the experiment was 27°C. The experiment was conducted to ascertain the elongation property of the prepared samples at a particular temperature. From the graph it is clear that the BM with 0% CR has the highest ductility and with addition of CR, the ductility of the CRMB reduces with 12% CRMB having the lowest ductility. By including crumb rubber, bitumen's ductility is diminished, a sign that the combination has become more brittle and rigid. This might be because bitumen is more flexible than crumb rubber and when CR is added in larger concentrations, it can reduce the mixture's capacity to expand and deform under stress. With decrease in ductility, fatigue as well as creep in the bituminous matrix decreased. In certain situations where flexibility is required, this can be an issue. To guarantee optimal performance, it's crucial to match the quantity of CR used with the intended characteristics of the finished product.

(a) (b)

Figure 9: (a) Briquette Mould (b) Ductility Testing Machine

Table 8: Results obtained for ductility test

CRMB %	Briquette Elongation (cm)			Mean Elongation
	Sample 1	Sample 2	Sample 3	
0%	76.8	75.8	76.6	76.40
5%	40	38	42	40
8%	28	26	24	26
10%	22.5	23	22	22.5
12%	18	16	14	16

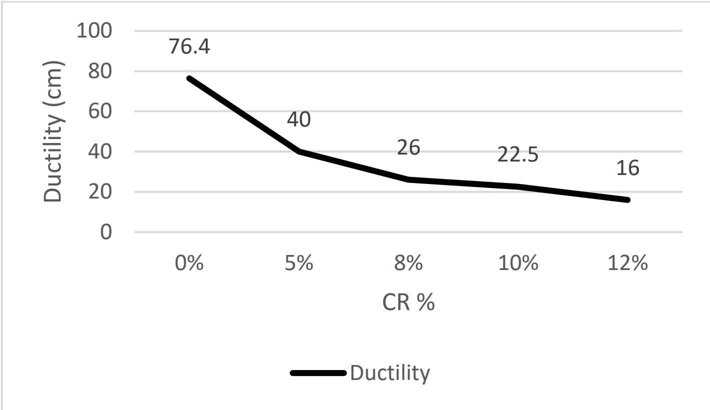

Figure 10: Ductility test results

d) Flash and Fire Point Test: The minimum temperature under the prescribed testing conditions at which the bitumen vaporizes is termed as its flash point [20]. It becomes vital to examine this bitumen feature because the hydrocarbon's volatiles are secreted by bitumen. It may catch fire when exposed to heat and high temperatures since it contains carbon. Under particular testing settings, the minimum heating point that causes BM to light up and burn is termed as its fire point. This experiment was executed to evaluate the safety and management of bitumen. This test assisted in confirming the material's suitability for storage, preservation, and shipment. The tests were also used to evaluate the standard of quality as well as purity of the bituminous mixes and to look for any possible pollutants. From the graph it was seen that as the CR was added to the bituminous mix, its flash and fire point increased with 12% CRMB having the highest flash as well as fire point because with addition of CR, the viscosity escalated and reduced the mix's volatility. This is because the CR particles have tendency to develop a framework of three-dimensional networks in the asphalt, which decreases the flexibility of the bituminous mix and raises the level of energy needed for them to evaporate, thereby increasing its flash and fire point. Additionally, this lessens the possibility of catastrophes such as explosions and fires while bitumen is being transported and stored. It was also noticed that with CR quantity increasing from 10% to 12% by weight of bitumen, the fire point of the bitumen sample increased significantly. The quality of bitumen samples enhanced with the addition of CR and such samples are more suitable to construction projects as they can be stored for a longer period of times and have less concentration of pollutants thereby having high quality.

Figure 11: Flash and fire point apparatus

Table 9: Results obtained for Flash and Fire Point Test

CRMB %	Flash point (°C)			Mean	Fire Point (°C)			Mean
	Specimen 1	Specimen 2	Specimen 3		Specimen 1	Specimen 2	Specimen 3	
0 %	285	280	275	280	294	295	288	292.33
5 %	287	281	279	282.33	301	297	292	296.66
8 %	288	293	282	287.66	298	307	293	299.33
10 %	289	293	290	290.66	310	305	310	308.33
12 %	300	296	298	298	333	333	330	332

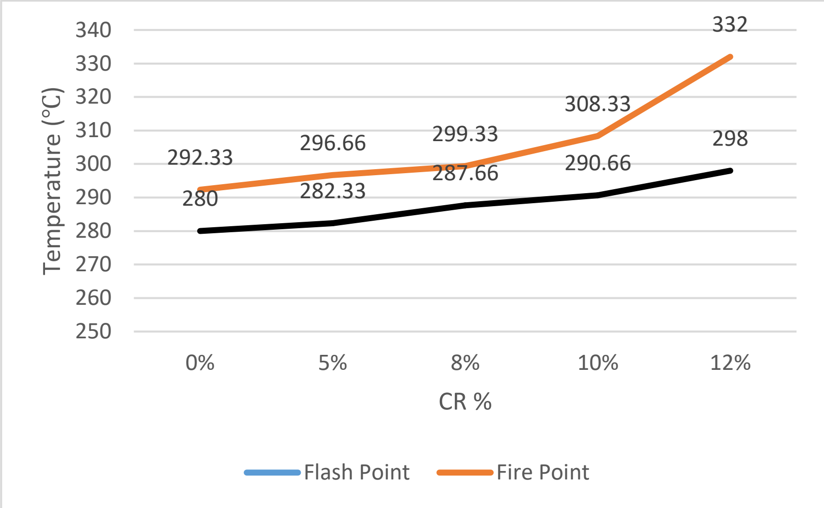

Figure 12: Flash and fire point results

e) Specific Gravity Test: The density of bituminous mix in relation to the density of the reference fluid at room temperature, typically considered at 25°C, can be characterized as bitumen's specific gravity. The instrument used for the test is known as pycnometer [20]. The test is carried out in obedience with IS: 1202-1978. Specific gravity test on bitumen samples was done to find the density of the BM. From the experiment it can be concluded that the virgin BM has the lowest specific gravity whereas the BM with 12% CR had the highest specific gravity which indicated that the 12% CRMB is a denser bitumen sample among all the samples. This is because the crumb rubber is much denser than bitumen and hence may have impacted the overall density of the mix. To establish whether the bitumen mix is suitable for its intended purpose, other qualities such as consistency, ductility, resistance to stresses due to heavy loads must also be considered as rise in specific gravity solely is not always a sign of enhanced performance or superiority.

Table 10: Results obtained for specific gravity test

CRMB %	**Sample No.**	**Weight in grams**				**Specific Gravity of Bitumen Mix**
		Pycnometer (w1)	Pycnometer + Water (w2)	Pycnometer + Bitumen (w3)	Pycnometer + Water + Bitumen (w4)	
0 %	1	64	124.6	94.8	125.2	1.01
	2	64	125	94.5	125.5	1.016
	3	64	124.3	95	125	1.02
Mean						**1.015**
5 %	1	64	125.5	95.3	126	1.016
	2	64	125.8	95.7	126.1	1.019
	3	64	125.6	95.5	126.2	1.02
Mean						**1.018**
8 %	1	64	125.5	95.6	125.8	1.029
	2	64	126.5	95.8	126.5	1.022
	3	64	126.5	96	126.5	1.032
Mean						**1.027**
10 %	1	64	125.6	96.2	126.8	1.038
	2	64	125.6	96.4	126.7	1.035
	3	64	125.6	96.5	126.9	1.041

Mean						**1.038**
12 %	1	64	125.6	98	127	1.042
	2	64.2	125.6	96.6	126.8	1.038
	3	64.1	125.8	97.7	127.2	1.041
Mean						**1.041**

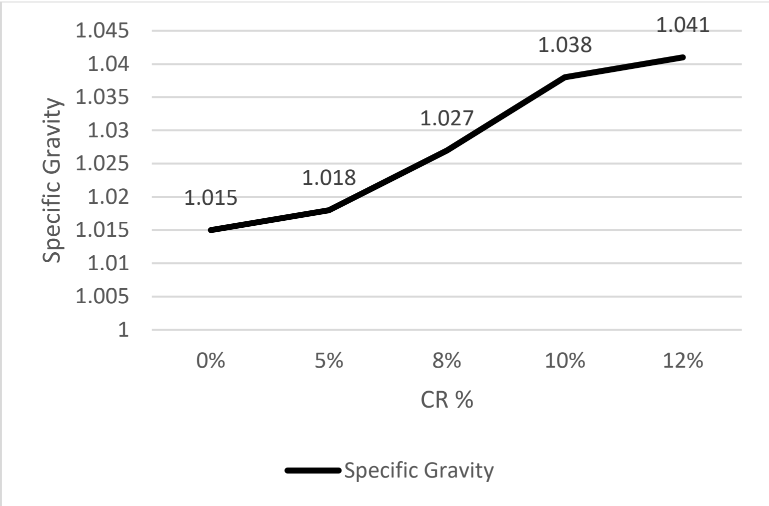

Figure 13: Specific gravity test results

5. COMPARISONS

The results of this research were compared to those of earlier studies and inferences were drawn. Through comparison it was made clear how crumb rubber efficiency may alter depending upon the bitumen grade being used. It was understood that for the same CR% the performance of the rubberized mixtures may differ due to difference in behavior of crumb rubber with different grades of bitumen utilized in the mix. Comparing the data below collected from various research studies with this study, we can say that the bitumen grade used in this study (60/70) shows better penetration property than the other bitumen grades when mixed with crumb rubber. When CR is added to bitumen of grade 60/70, the penetration is far less than that seen in other bitumen grades. In this study, when 12% CR is added to bitumen 60/70, penetration value is 33mm. when comparing this to the penetration values of other studies mentioned below, we can say that bitumen 60/70 has the lowest penetration with bitumen grade 80/100 used in [28] being the closest to it with penetration of 42mm. Therefore for achieving minimum penetration in an asphalt mix, bitumen 60/70 should be considered among the other grades when CR added to it.

According to the comparison done in the below table among the 5 research studies (excluding this study), for 12% CR additive in the asphalt mix, clearly in [24] with bitumen grade 160/220 the softening point is highest with value of 62.2℃. But now when the comparison of softening point in [24] is made with that obtained in this study we can see that the softening point obtained here with bitumen 60/70 was even higher and equal to 63.5℃. Hence for the same CR percentage we can conclude that bitumen 60/70 shows higher softening point as compared to bitumen 160/220 which means bitumen 60/70 is thermally more stable and resistant to bitumen distortion, therefore is more suitable and should be considered for pavement construction in regions of hot climatic conditions. When the ductility of bitumen 80/100 mixed with CR quantity of 12% by weight of bitumen as used in [28] is compared to the ductility of bitumen 60/70 with same CR% as used in this study, the ductility of bitumen mix 60/70 is less than that of bitumen 80/100. Hence bitumen 60/70 is subjected to less fatigue and creep. Similarly comparing bitumen 70/100, 60/80 and 60/70 for 10% CR quantity added to the BM, ductility of bitumen 60/80 is lowest and that of 70/100 is highest indicating bitumen 70/100 is too ductile or soft for withstanding heavier loads. The difference of ductility for bitumen 60/80 and 60/70 when 10% CR is added to the BM is not much and in fact by adding 15% CR to the 60/80 bitumen the ductility is almost similar to that of 60/70 bitumen with 12% CR added to it. Hence more CR is to be used in case of 60/80 bitumen grade to achieve ductility nearly equal to the ductility of 60/70 grade with 12% CR addition. Also bitumen 60/70 is much more economical than other bitumen grades hence the reason why bitumen 60/70 is mostly preferred for pavement construction these days.

Table 11: Comparison table for penetration test

Penetration test	**CR %**	**Value (mm)**
[25]	10%	45
	15%	43
	20%	39
[26]	4%	52
	8%	48
	12%	43
	16%	42
	20%	41
[24]	3%	116
	6%	100
	9%	81
	12%	62
	15%	53
[27]	5%	60
	10%	55
	15%	45
	20%	41
[28]	4%	74
	8%	53
	12%	42
	16%	25
This study	5%	60
	8%	48.66
	10%	41
	12%	33

Table 12: Comparison table for softening point test

Softening point test	CR %	Value (°C)
[25]	10%	56
	15%	60
	20%	65
[26]	4%	55.2
	8%	57.4
	12%	60.6
	16%	62.2
	20%	64.9
[24]	3%	46.4
	6%	52
	9%	56.3
	12%	62.2
	15%	67.9
[27]	5%	51
	10%	52.5
	15%	53.5
	20%	54
[28]	4%	50
	8%	52
	12%	56
	16%	58
This study	5%	51.5
	8%	53.5
	10%	57.7
	12%	63.5

Table 13: Comparison table for ductility test

Ductility test	CR %	Value
[25]	10%	80
	15%	92
	20%	96
[27]	5%	15
	10%	16
	15%	14
	20%	12
[28]	4%	22
	8%	20.5
	12%	18
	16%	14.5
This study	5%	40
	8%	26
	10%	22.5
	12%	16

From the above statistics we can say that CRMB consisting of bitumen 60/70 shows much better properties as compared to CRMB consisting of any other bitumen grade. Also bitumen 60/70 is much cost friendly than other grades of bitumen which can play a crucial role in projects with heavy investment. Therefore using bitumen 60/70 should be considered.

6. CONCLUSION

Compared to untreated binders, bitumen treated with rubber is often thicker and tends to exhibit greater adhesive bonding when combined with aggregates. In this study experimental investigation was carried out on virgin bitumen as well as on the modified bitumen. The test findings show the penetration and ductility of the CRMB samples decreased when the CR concentration grew from 0% to 12%. Reduced penetration improved the uniformity and flow resistance of the bitumen binder, the rigidity of the rubber binder, and the resistance to rutting. Additionally, CR decreased the bitumen's ductility, which decreased fatigue as well as creep in the bituminous matrix. Also due to addition of CR, softening point of CRMB increased making such bitumen samples much more suitable for use in hot climatic conditions as such samples are thermally more stable and loss of strength is reduced to a far extend. Increasing the proportion of rubber in the bituminous mixture also enhanced flash and fire point. This is because the volatility of the BM reduces with addition of CR. This property is achieved due to the unique 3-D structure that rubber particles form in the bitumen mix making it difficult for the particles to evaporate thereby increasing its flash and fire point. Specific gravity of CRMB also increased but the increase is very less. In other words, addition of CR didn’t have any significant impact on the specific gravity of the modified mix. Therefore, using reclaimed CR can both improve the efficiency of asphalt surfaces and offer a secure method of getting rid of these non-biodegradable materials. The procedure is environment-friendly.

Declarations

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