

# Evaluation of Marshall Stability Characteristics of Crumb Rubber Modified Bituminous Mixes

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## Abstract:

Crumb rubber modified bitumen improved the physical properties of bitumen and increased Marshall Stability values of the mixes. The addition of crumb rubber reduces the tyre waste as an environmental threat, improving the properties of the bitumen to some extent and hence could provide a more durable life for the flexible pavement when used in the correct amount. The penetration values for the VG 30 bitumen with crumb rubber decrease considerably. The penetration value diminishes with an increase in the concentration of the modifier. The penetration value for clean bitumen is 67.4, which decreases to 61, 58, and 49 upon modification with 5CR, 10CR, and 15CR, respectively. Marshall Stability characteristics of bitumen modified with crumb rubber exceed those of untreated mixtures. The stability values also show the gradual increase in with increase in percentage of modifier content. With increase in the concentration of modifier, the binder becomes more viscous so it can be proved that the stiff binder will result in higher stability value of mix. With the increase of crumb rubber from 5% to 15%, the values ranged from 10% to 25% increase.

**Keywords:** Bitumen; Marshall Stability; Crumb rubber; Flexible pavement; Modifiers.

## Introduction:

Flexible pavements are widely employed in highway construction due to their ease of construction, rider comfort, good durability and economy (Huang, 2004; Yildirim, 2007). Bituminous concrete is one of the most commonly used materials for flexible pavements which are composed of aggregates and bitumen binder. Aggregates constitutes nearly 95% by weight of hot mix asphalt (HMA) mixture and bitumen binder 5% by weight (Airey, 2003). A typical HMA mix consists approximately 85% aggregates, 10% binder, and about 5% air voids by volume. Engineering characteristics of bituminous pavements depend mainly on aggregate characteristics, binder properties, traffic loading, weather conditions and construction procedure (Kalantar et al., 2012; Mashaan et al., 2014).

Rapid urbanization, continuous increase in vehicle traffic resulted into the increased load per axle and tire pressure. Consequently, conventional bituminous pavements have often shown premature failures, like rutting, fatigue cracking, ravelling and moisture induced damage (Chen et al., 2002; Lu & Isacson, 1998). In conventional bituminous mixtures, bitumen binders do not show an acceptable degree of resistance to sever environmental and traffic loading, and hence modification of bitumen binder become necessary to enhance the performance of pavement and extend the service life (Navarro et al., 2004; Yildirim, 2007).

Over the recent decade, polymer and waste derived material modified bitumen have proved to be very efficient method to improve the engineering properties of asphalt mixtures (Partal et al., 1999). Among various additives, crumb rubber obtained from waste automobile tires became the most promising additive because of environmental, economical and mechanical advantage (Attia & Abdelrahman, 2009). Disposal of the waste automobile tires has emerged to be one of the major environmental concern as they are not biodegradable and

accumulating day by day worldwide. Utilisation of waste tire rubber as an additive in bituminous mixture thus could lead to an environmentally beneficial waste disposal alternative as well as a improvement of pavement materials characteristics (Gibreil & Feng, 2017; Bilema et al., 2024).

Experimental works show that crumb rubber modified asphalt have higher elastic, resistance to fatigue, better resistance to rutting and higher durability compared to the conventional asphalt mixtures (Shen et al., 2007; Xiao et al., 2007). Recent works show that modification of bitumen with crumb rubber improves high temperature stability, crack resistance and moisture susceptibility of asphalt pavement (Afonso et al., 2024; Wang et al., 2025). It has also been observed in research works that with the use of optimum rubber content and optimum processing condition of rubber modified bitumen; there is significant improvement in Marshall Stability, flow and resistance to rutting of asphalt mixtures (Arabani & Tahami, 2017; Chen et al., 2024).

The Marshall Stability method is one of the most commonly adopted techniques for evaluating the strength and volumetric properties of bituminous concrete mixes. Parameters such as Marshall Stability, flow value, density, air voids, and voids filled with bitumen are widely used to assess the suitability of modified asphalt mixtures for pavement applications (Singh et al., 2013). Several experimental investigations have reported that crumb rubber modified bituminous mixes provide superior resistance against permanent deformation and improved load-carrying capacity under heavy traffic conditions (El-Sayed & Abdelrahman, 2024; Khan et al., 2024).

The purpose of the present research is to find out the effect of crumb rubber modification on the strength properties of bituminous concrete mixes using VG-30 bitumen. Marshall Stability tests were performed for mixes with different percentages of crumb rubber and compared with conventional bituminous mixes. The study evaluates the potential of crumb rubber modified bitumen in enhancing the pavement performance as well as recycling of waste tire materials in road construction.

### **Experimental methodology:**

Hot mix asphalt generally consists of combination of different size of aggregates with mineral fillers, uniformly mixed and coated with bitumen, each having its own particular characteristics, which will be more suitable to specific design and construction purposes. To set up a laboratory study and investigate effect of aggregate properties on the HMA aggregate structure and the stability of bitumen pavements, aggregate content and source properties have to be properly taken into account together. Aggregates were tested in this study, and the stability of aggregates for use in bitumen construction was determined by evaluating the material in terms of the following.

1. Size and grading
2. Particle shape
3. Absorption
4. Toughness

Properties of crumb rubber were also examined i.e. penetration, ductility, softening point, viscosity etc.

**Mix Preparation:** Approximately 1200 grams of aggregates and filler were cooked to a temperature ranging from 175 to 190°C. The compaction mold assembly and rammer are cleaned and maintained at a pre-warmed temperature of 95°C to 150°C. The bitumen binder was heated to a temperature ranging from 150°C to 175°C. In an initial bitumen trial rate of 4.5% by weight of the mineral aggregates, the heated aggregates and bitumen were thoroughly combined in a temperature range of 154 to 160°C. The mixture was positioned in a preheated mold and crushed using a rammer with 75 blows on each side at a temperature of 140°C to 155°C. The mass of the combined aggregates used for the sample preparation may be adjusted to achieve a compacted thickness of

63.5 ± 3 mm. The bitumen content in the subsequent trial was increased by 0.5%, and the aforementioned process was consistently applied. The number of trials is set.

**Result and Discussion:**

The Marshall Method of mix design is endorsed by MoRTH for the formulation of bituminous concrete mixes and has been utilized in the current study for designing various mix types. The bituminous concrete mixtures were formulated using aggregates and four varieties of binders: VG 30 bitumen, VG 30 bitumen with 5% crumb rubber, VG 30 bitumen with 10% crumb rubber, and VG 30 bitumen with 15% crumb rubber. The optimum binder content (OBC) and further Marshall parameters of bituminous concrete mixtures were assessed. The permanent deformation characteristics of various mixtures were examined using the wheel tracking test. Marshall Stability Graphs were constructed to analyze the behavior.

**Optimum Bitumen Content (OBC)**

Semi-dense bituminous concrete (SDBC) is the predominant wearing course utilized on National Highways in India. According to MoRTH specifications from 2011 in India, SDBC mixes with a nominal aggregate size of 13 mm and a layer thickness between 25 mm and 40 mm may contain 4.5-6% binder content by weight of the whole mix. The Marshall specimens were made and evaluated at three distinct bitumen contents: 4%, 5%, and 6%. To ascertain the optimal binder content, three specimens were constructed for each binder content level. The OBC was determined by evaluating characteristics of Marshall Stability, including low values, total void volume, voids filled with bitumen (VFB), and the unit weight of the bitumen concrete mix as presented in Table 1. Table 2 presents the Marshall characteristics of several bituminous mixtures corresponding to their specific bitumen concentration. The uniform gradation of all mixes attributes the calculations of the OBC to the binder content.

**Effect of Crumb rubber Marshall Stability Parameters**

The results or various tests are given below and comparison of various properties and strength parameters are discussed with the help of graphs.

**Marshall test results.**

Table 1 presents the diverse Marshall parameters assessed by the Marshall testing apparatus. The diverse characteristics for numerous mixtures were computed to evaluate the outcomes and determine the optimal bitumen value and the most effective percentage of crumb rubber to utilize at that bitumen content.

**Table 1:** Data for plotting curves

Sample No.	Crumb rubber (%)	Bitumen content (%)	Mean Stability Value (kg)	Mean Flow Value (mm)	Mean Vv. (%)	Mean VFB (%)	Mean Unit Wt.
1	0	4	1045	2.71	4.26	63.66	1.989
2	0	5	1207	3.09	3.74	73.80	2.001
3	0	6	1064	3.29	3.58	75.63	2.005
4	5	4	1267	3.30	4.83	63.62	1.980
5	5	5	1372	3.31	3.90	70.90	2.002
6	5	6	1127	3.39	4.17	71.65	1.997
7	10	4	1179	3.17	4.41	66.27	1.992

8	10	5	1627	3.18	3.75	71.83	1.989
9	10	6	1360	3.51	3.80	73.35	1.938
10	15	4	1313	3.92	4.23	67.31	1.898
11	15	5	1690	4.13	3.53	72.90	2.002
12	15	6	1233	4.59	3.57	74.98	2.001

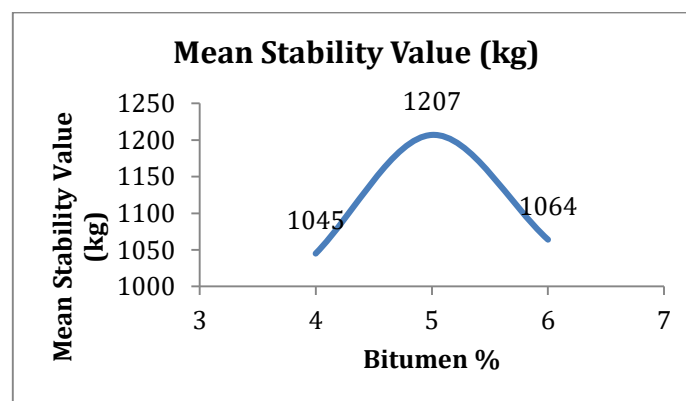
### Marshall test results at 0 % Crumb rubber

The relationship between Marshall Stability and bitumen content for the conventional mix demonstrates a characteristic parabolic tendency. Stability rises from 1045 kg at 4% bitumen to a maximum of 1207 kg at 5% bitumen, then declines to 1064 kg at 6% bitumen. The approximately 15.5% increase between 4% and 5% bitumen is due to superior aggregate coating and increased inter-particle bonding, which promote effective stress transfer. The below reduction (~11.9%) at higher binder content indicates that added bitumen act as a lubricant so the internal friction and structural strength reduces.

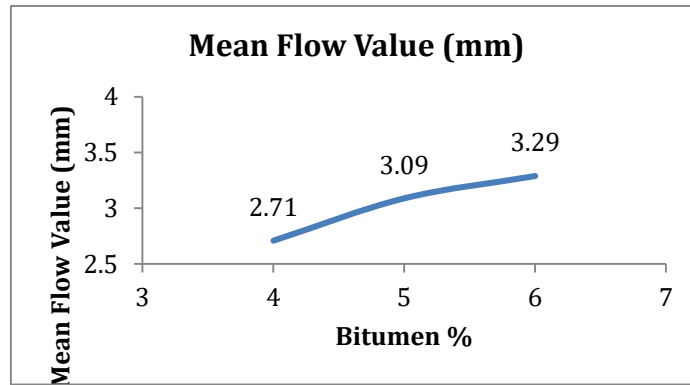
The readings of flow are found to increase in the order of 2.71, 2.85, 3.14, 3.29 from 5% to 9% bitumen content and this increment found to be ~21.4%. The flow rate increases as we add more bitumen in the mix, the more flexibility of the mix. Increased flow values show the more flexibility of the mix and also shows the more propensity to permanent deformation under repeated cyclic loading.

The air voids reduces from 4.26% to 3.58% from 5% to 9% bitumen content with an increment of ~15.9%. The addition of more binder has filled up the air voids so density increases gradually. The Voids Filled with Bitumen (VFB) increases from 63.66% to 75.63% from 5% to 9% bitumen content with an increment of ~18.8% showing good spread and cohesion of the mix. The unit weight decreases slightly from 1.989 g/cc to 2.005 g/cc from 5% to 9% bitumen content.

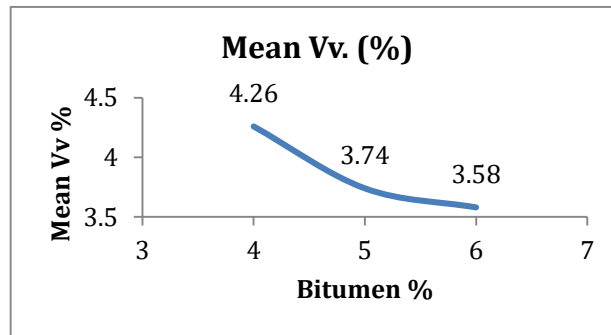
Average mix gives optimum result at 5% bitumen content showing strength, flexibility and durability (as given in fig. 1-5)



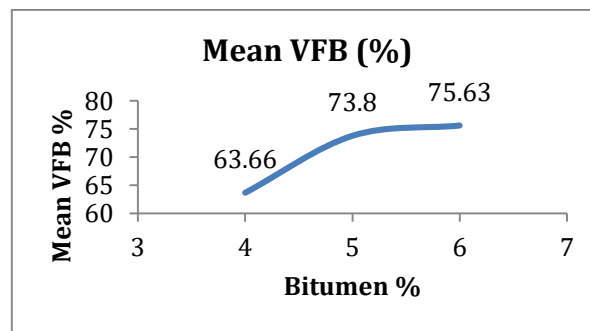
**Figure 1:** Stability value of asphalt mixtures against bitumen content



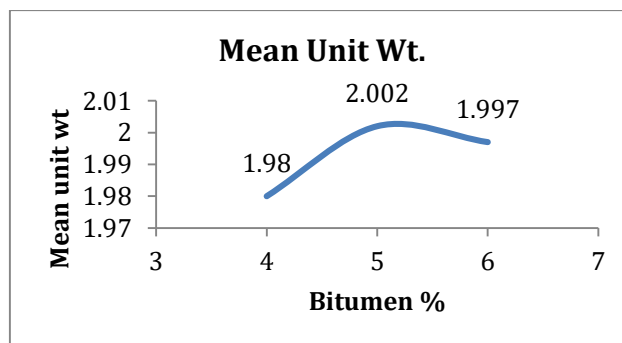
**Figure 2:** Flow values of asphalt mixtures against bitumen content



**Figure 3:** Volume of voids of asphalt mixtures against bitumen content



**Figure 4:** Volume of voids filled with bitumen against bitumen content



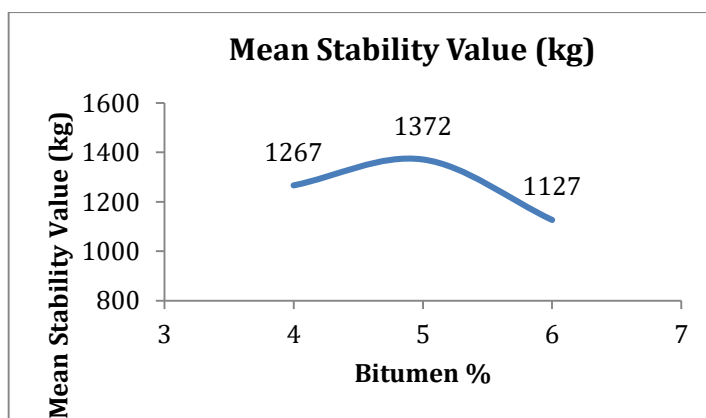
**Figure 5:** Unit weight against bitumen content

### Marshall test results at 5 % Crumb rubber

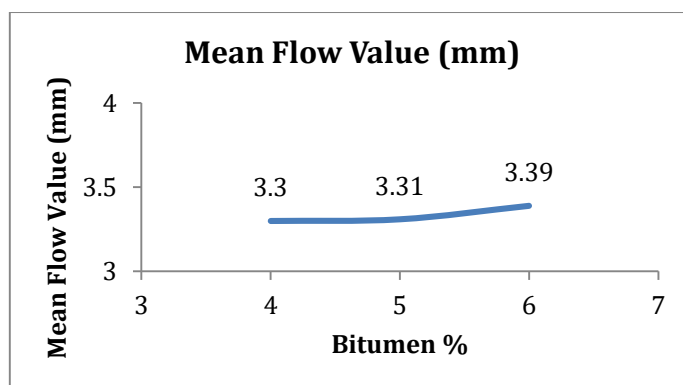
Adding 5% crumb rubber improves the Marshall Stability considerably from 1148 to 1372 kg at 5% bitumen content showing an improvement of about 13.7% over control mix. This is due to enhanced viscosity and elastic property of the modified binder and resistance to deformation increase.

Flow increases slightly from 3.30 mm to 3.39 mm showing that crumb rubber addition increases elasticity of the mix without affecting much of deformation resistance. Air void decreases from 4.83 % to 3.90 % thereafter it slightly increases with the increase in binder content and thus implies that more bitumen content is bad.

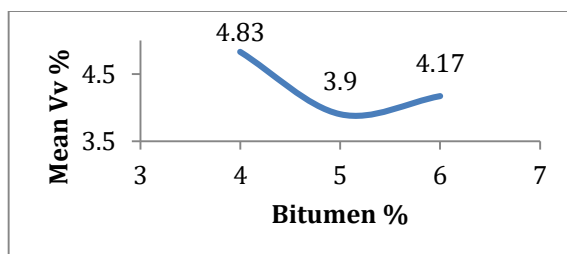
VFB increases continuously from 63.62 % to 71.65 % meaning there are more voids filled with binder and also the binder is being utilized effectively. The unit weight values remain constant with only slight fluctuations due to the lesser specific gravity of crumb rubber. Mechanical property improves without adversely affecting the volumetric values as shown in figure 6-10.



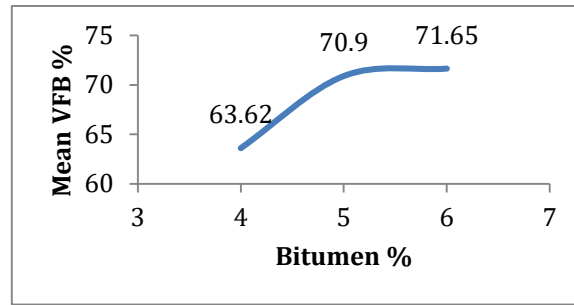
**Figure 6:** Stability value of asphalt mixtures against bitumen content



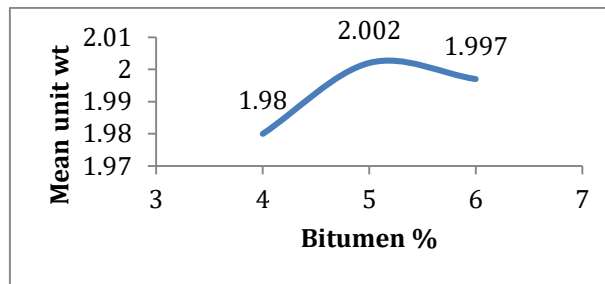
**Figure 7:** Mean Flow values of asphalt mixtures against bitumen content



**Figure 8:** Volume of voids of asphalt mixtures against bitumen content



**Figure 9:** Volume of voids filled with bitumen against bitumen content



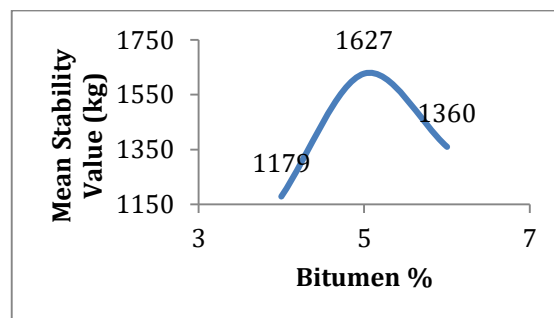
**Figure 10:** Unit weight against bitumen content

### Marshall test results at 10 % Crumb rubber

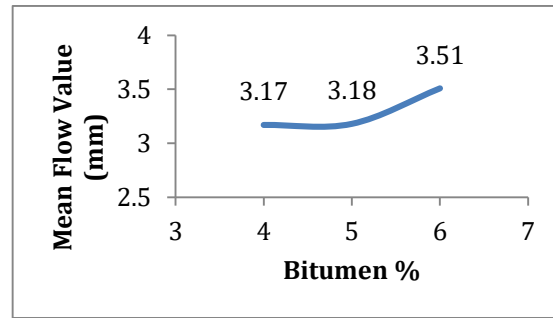
An obvious improvement in Marshall Stability is seen at 10% crumb rubber content, where stability increases from 1179kg at 4% bitumen to 1627kg at 5% bitumen (an increase of close to 38%). This is a 34.8% increase compared to the traditional mixture at its optimum bitumen content, proving that crumb rubber is an effective strengthening modifier.

The increase is because the binder stiffness, as well as the elastic recovery of the binder, increases, and thus increases the resistance to permanent deformation. The flow value shows a modest increase from 3.17mm to 3.51mm which shows the measured benefit to flexibility, without excessive deformation.

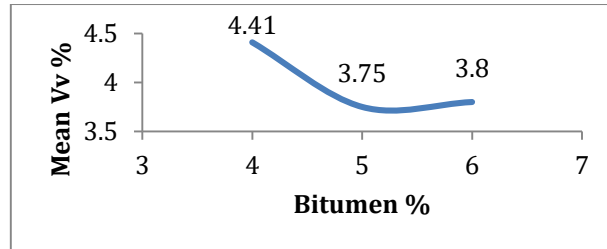
The air void content decreases from 4.41% to 3.8%, which demonstrates better compaction and thus lower permeability. However, the unit weight only shows a small decrease of about 2.7%, due to the lower density of crumb rubber particles. It would appear that 10% crumb rubber gives a good balance of strength and deformation resistance and is therefore a suitable level of modification as presented in Figure 11-15.



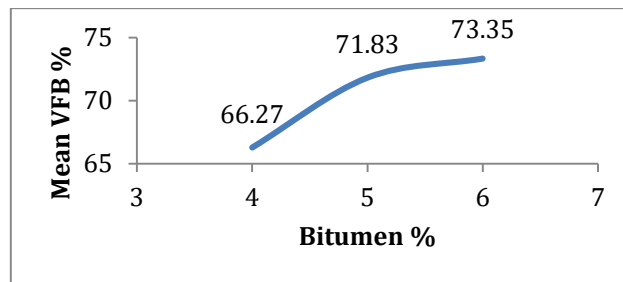
**Figure 11:** Stability against bitumen content



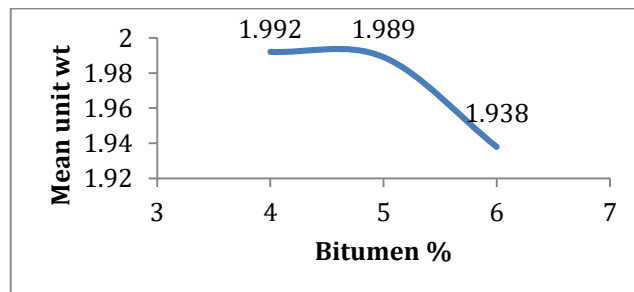
**Figure 12:** Mean Flow Value against bitumen content



**Figure 13:** Volume of voids against bitumen content



**Figure 14:** Volume of voids filled against bitumen content



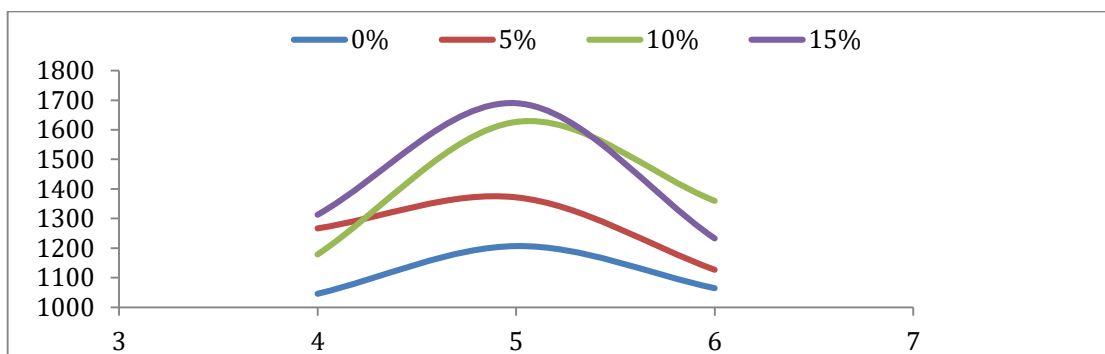
**Figure 15:** Unit weight against bitumen content

### Marshall test results at 15 % Crumb rubber

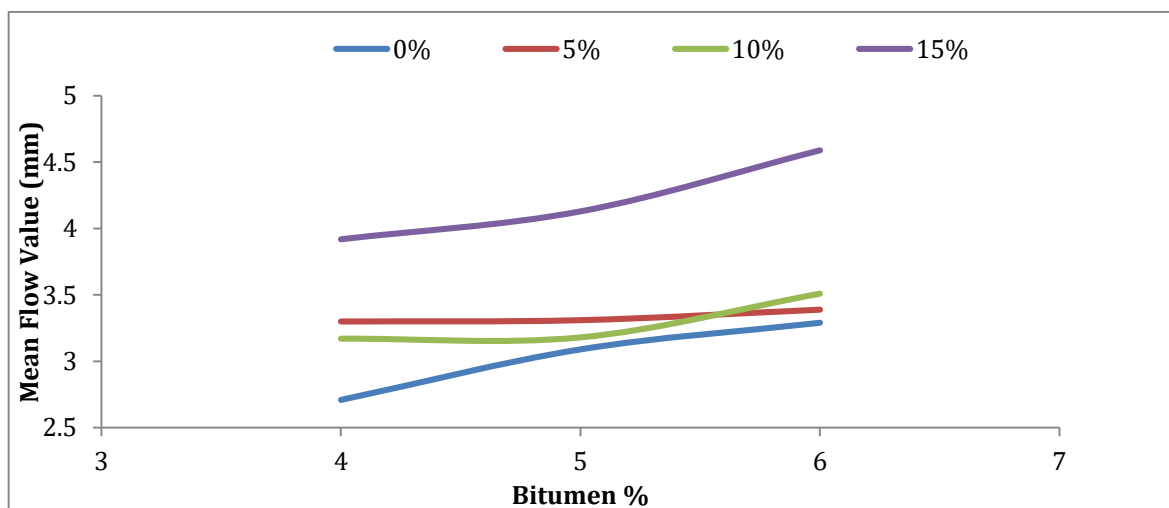
At a crumb rubber content of 15%, the Marshall Stability reaches its maximum value 1690 kg at 5% bitumen, which represents almost a 40% increase from the original mix. High value of stability improvement is mainly due to the stiffness and elastic nature of the modified binder. On the contrary the flow value increased from 3.92 to 4.59 mm (~17%) that means more deformation possible. The amount of air voids reduced to about 3.5%, thus, shows dense mix structure but excess binder modification would be adversely effects the workability and future behavior of pavement mixture. So the higher content of crumb rubber provides strength along with the trade-off of increasing flexibility and vulnerability to rutting.

### Comparison of stability and flow values

Figure 16 illustrates the comparison of stability test results. The results indicate that the Marshall Stability values of bitumen modified with crumb rubber exceed those of unaltered mixtures, with stability values rising in accordance with increased modifier concentration. This is due to the rise in modifier content, resulting in a more viscous binder, confirming that a rigid binder leads to an elevated stability value of the mixture. The optimal bitumen content was determined to be 5%.

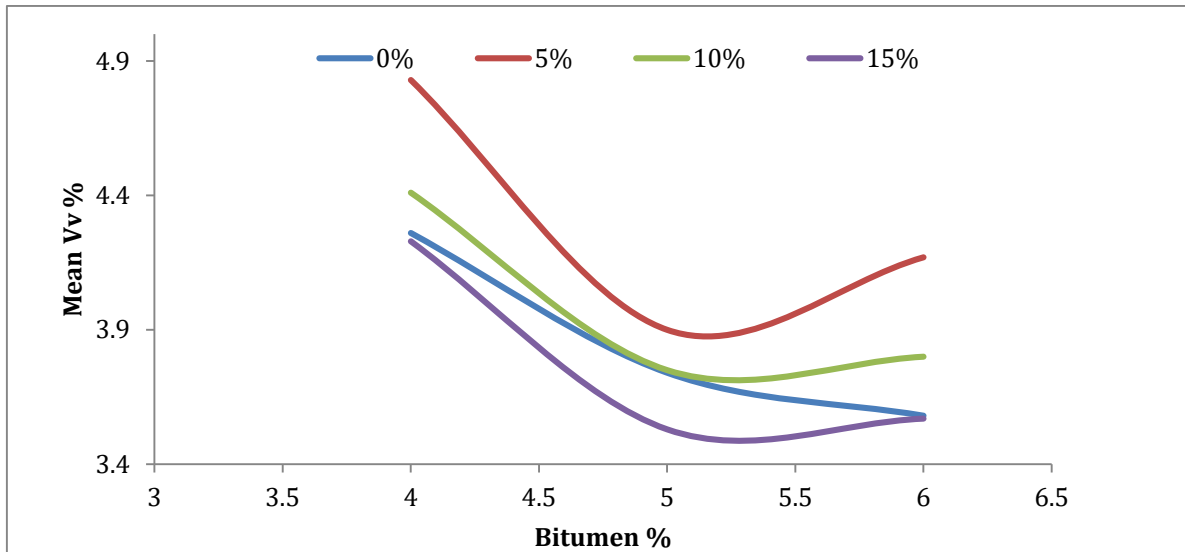


**Figure 16:** Comparison of stability values of mixes at different bitumen content

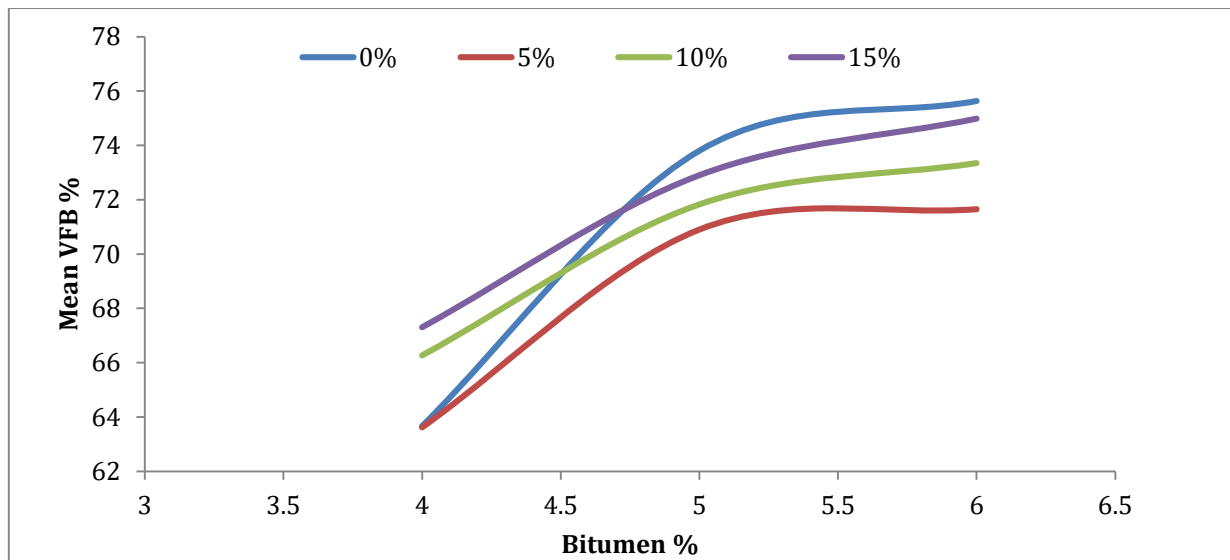


**Figure 17:** Comparison of Mean Flow Value of mixes at different bitumen content

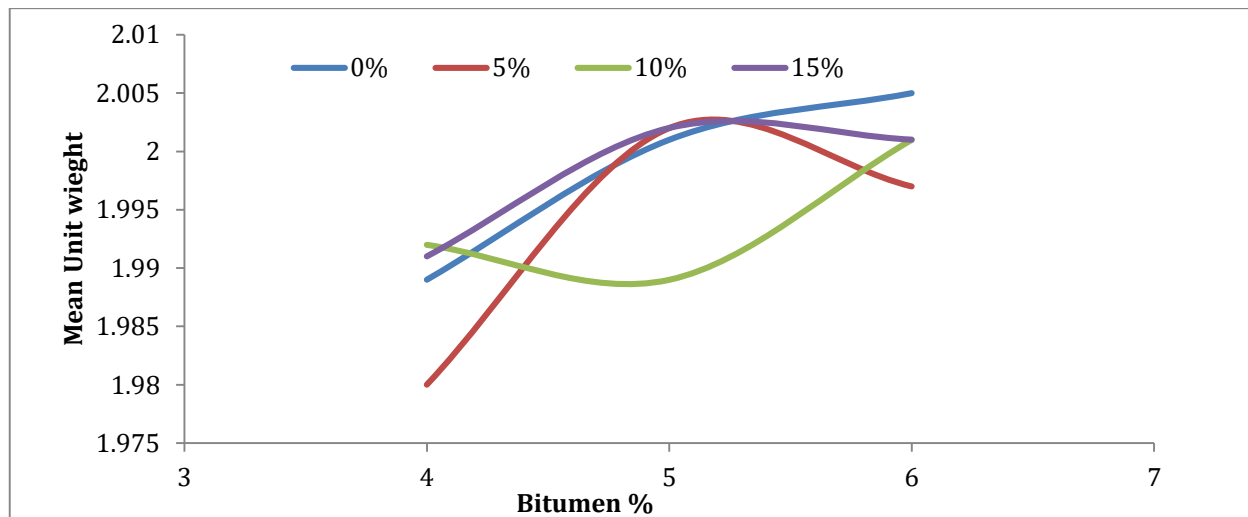
Figure 17 illustrates the flow values of the asphalt mixtures in relation to bitumen content. The results indicate that the flow values adhere to the normal pattern of Marshal Flow graphs with increasing bitumen concentration, and the values remain within allowed limits for 10% crumb rubber. However, raising the modifier content from 10% to 15% results in a flow value beyond the prescribed limits. The results indicate that at 10% crumb rubber and 5% bitumen content, the Marshall Stability value is maximized, while the corresponding flow value remains within acceptable limits. Therefore, it can be asserted that a 5% bitumen concentration is the optimal level for the asphalt mixture.



**Figure 18:** Comparison of Volume of voids of mixes at different bitumen content



**Figure 19:** Comparison of volume of voids filled of mixes at different bitumen content



**Figure 20:** Comparison of unit weight of mixes at different bitumen content

Based on the graph, it is quite evident that there is a general trend for the average flow value of all mixes to increase with the increase in bitumen content. The conventional mix shows an increase from 2.71 mm to 3.29 mm for bitumen content from 4% to 6%. This indicates about 21.4 % increase in the flow value. Similar trend has been shown by the crumb rubber modified mixtures as well where flow values range between 3.30 and 3.39 mm for 5% crumb rubber, between 3.17 and 3.51 mm for 10% crumb rubber and between 3.92 and 4.59 mm for 15% crumb rubber. The increase in flow values as bitumen content increases can be attributed to increase in plasticity of the mix thus greater deformation under pressure applied. Further, crumb rubber adds elastic characteristic to the mixture however at higher concentration of 15%, the mix is too flexible and hence it deforms more. Mixes with 10% crumb rubber shows flow value within acceptable range whereas with 15% it shows high flow value and hence 10% crumb rubber and 5% bitumen mixture is assumed to be a suitable mix where there is a perfect balance between flexibility and stability.

As bitumen concentration is increased, the value of air voids ( $V_v$ ) decreases for all mixtures. Conventional mixture shows a decrease in air voids from 4.26 % to 3.58 % as the bitumen content increase from 4% to 6%. This is about 15.9 % decrease. The same trend is noticed in crumb rubber modified mixtures. Values for 5% crumb rubber range from 4.83 % to 4.17%, for 10% from 4.41% to 3.80% and for 15% from 4.23 % to 3.57 %. Decrease in the air voids is primarily due to replacement of voids by bitumen as and when the percentage of binder is increased and better coating of the aggregates by the binder. Also, crumb rubber increases viscosity and better compaction is achieved. However very low percentage of air voids would increase the probability of bleeding and reduce the durability of the mix. The results indicate that all mixtures achieve suitable air voids value at 5% bitumen which signifies it as optimum bitumen content and 10% crumb rubber as optimum value for modifier.

We see from void filled with bitumen (VFB) analysis, that there is a consistent increase with the increase in the percentage of bitumen concentration for all mixtures. For the normal mixture, VFB increase from 63.66% to 75.63% with bitumen concentration increasing from 4% to 6%. This indicates approximately 18.8% increase. For crumb rubber modified mixtures with 5%, 10% and 15% crumb rubber content, VFB increases from 63.62% to 71.65%, from 66.27% to 73.35% and from 67.31% to 74.98% respectively. Increase in VFB means that a greater percentage of air voids are filled by the binder thus increase the cohesion and durability of the mixture. The addition of crumb rubber increases binder viscosity and adhesion so that the void filling is more effective. Too high VFB at higher binder concentration could result in bleeding and less resistance to deformation. It may be concluded that 5% bitumen concentration gives a good balance of void filling and structure while 10% crumb rubber improve the durability without over filling the voids by the binder.

From the unit weight analysis, there is hardly any significant change with respect to the bitumen concentration and the crumb rubber content. The unit weight for the normal mixture increases slightly from 1.989g/cc to 2.005g/cc for 4% to 6% bitumen content. For crumb rubber modified mixture, the unit weight increases from 1.98 to 2.002g/cc for 5% crumb rubber content, 1.992 to 2.001g/cc for 10% crumb rubber content and 1.991 to 2.002g/cc for 15% crumb rubber content. The slight increase in unit weight with bitumen concentration could be due to better compaction and aggregate arrangement. Crumb rubber modification increases the VFB of the mixture. Due to lower specific gravity, crumb rubber does have a little effect but not a significant impact on the density. The mixture shows desirable unit weight values, thus can be used for pavement applications..

## Conclusion:

Based on the findings presented in the preceding chapters, the subsequent conclusions are derived: The study clearly indicates that crumb rubber-modified bitumen enhances the physical properties of bitumen and the Marshall Stability values of the mixtures. The incorporation of crumb rubber not only mitigates tyre waste, an environmental burden, but also enhances bitumen properties, potentially extending the lifespan of flexible pavements when used in appropriate quantities. The subsequent points merit attention from the conducted study:

- The penetration levels markedly diminish for VG 30 bitumen combined with crumb rubber. The penetration value decreases as the concentration of the modifier increases. The penetration value for clean bitumen is 67.4, which decreases to 61, 58, and 49 upon modification with 5CR, 10CR, and 15CR, respectively.
- The softening point rises with an increase in the percentage of modifiers. The softening point rises as the bitumen's viscosity increases with the incorporation of crumb rubber. The softening point of VG 30 bitumen rises from 58 to 78 degrees Celsius with the addition of 15% crumb rubber. Crumb rubber modified bitumen is suitable for usage in high-temperature regions.
- The viscosity of VG 30 bitumen is 0.5 Pas at 135 degrees Celsius. The use of 5%, 10%, and 15% crumb rubber elevates the viscosity to 1.5, 2.24, and 4.25 Pa.s, respectively. The augmentation in modifier content led to a rise in viscosity, as the incorporation of crumb rubber into bitumen enhances viscosity due to the swelling and sticky properties of the crumb rubber.
- The Marshall Stability ratings of bitumen treated with crumb rubber exceed those of unaltered mixtures. The stability values further increase with a rise in the modifier content. The increase in modifier concentration leads to a more viscous binder, so confirming that a stiffer binder enhances the stability value of the mixture. Increasing crumb rubber percentage from 5% to 15% resulted in a 10% to 25% improvement.

The optimum binder concentration (OBC) for the mixtures is 5%. The optimal dose of crumb rubber-modified bitumen is determined to be 5%, as all Marshall parameters remain within acceptable ranges and the Marshall Stability value is maximized at this proportion.

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