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# Experimental Investigation of Bituminous Concrete Mixes Using Conventional Bitumen and Crumb Rubber Modified Bitumen

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## Abstract

**Objectives**: To find the suitability of Bituminous Concrete (BC) Grade-II mix as a pavement surface course layer using conventional bitumen and modified bitumen. **Methods:** The present research is carried out by conducting the Marshall stability test on the bituminous mixes by using Crumb Rubber Modified Bitumen (CRMB), also known as modified bitumen, on the Bituminous Concrete Grade-I (Gr-I) and Bituminous Concrete Grade-II (Gr-II) mixes. The gradation for the bituminous mixes is achieved by the trial and error method to obtain the suitable Job Mix Formula (JMF). Samples were prepared for varying percentages of conventional and crumb rubber modified bitumen, ranging from 5.0% to 6.25% by weight of bitumen. The Marshall parameters are analysed for different percentages of bitumen and modified bitumen. **Findings:** The Optimum Binder Content (OBC) for the crumb rubber modified bituminous mixes is 0.3% lower than the conventional bituminous mixes, and the mix prepared with modified bitumen showed a higher stability value of 20.2%, which greatly helps in increasing the service life of the pavement. In addition, the modified bitumen exhibited less flow than the conventional bituminous mix, indicating that it was less susceptible to temperature and enhancing the pavement's durability. Based on the research findings, it is more suitable to use BC Gr-II as a surface course layer on all the important highways than BC Gr-I. The research findings help to choose the grade of bituminous concrete to be used in the Indian context. **Novelty:** The novelty of the study lies in its approach to using waste materials in pavement construction, reducing the use of natural resources, reducing the cost of construction, enhancing the durability of pavement surfaces, and simultaneously mitigating the waste disposal problem.

**Keywords:** Bituminous Concrete; Marshall Stability; Crumb Rubber Modified Bitumen; Service Life; Waste Disposal

# 1 Introduction

Roads are considered very important for economic development, and a well-established road network is crucial for the progress of any developing country. India, being a developing nation, faces challenges in its transportation infrastructure, with issues like the availability of men, materials, and money. Many studies and published papers have advocated the use of waste materials in the construction of roads, which address issues of preservation of natural resources, reducing the cost of construction, and environmental issues related to the disposal of waste products[(1)]. The generation of waste has become a major environmental concern. The proper disposal of waste poses challenges, and to tackle this issue, the Indian government has initiated the 'Swachh Bharat Abhiyan', emphasizing the four R's: Reuse, Reduce, Recycle, and Recover. There is a need to design bituminous concrete mixes to get a strong and durable pavement surface. It can be achieved through the proper selection of materials to meet the standards, specifications, economics, environmental concerns, etc. The bituminous mixes should meet basic requirements such as workability, stability, density, minimum air void content, etc.[(2)]. Crumb rubber is a waste material derived from discarded tyres. In India, a significant number of tyres, up to several hundred million, are disposed of annually. Among them, 20% undergo the process of retreating or reusing, and the remaining 15% is diverted to various alternative purposes. The residue is added to landfills, stockpiles, or illegal dumps. In India, about 45-50% of the waste yielded from these discarded tyres is causing disposal problems that necessitate attention and should be addressed as a matter of priority[(3)]. Utilizing crumb rubber as a modifier in bitumen enhances the strength of the bituminous mixes[(4)], and the majority of the research was carried out on adding crumb rubber in a dry process method[(5,6)]. The research studies suggest the use of crumb rubber in the range of 5% to 20% in a dry process method. In addition, the studies carried out using crumb rubber modified bitumen showed higher Marshall stability values of up to 25% compared to conventional bituminous mixes[(7)]. In addition, the modified bitumen helps sustain more climatic variations, a high traffic load[(8)] and a better riding surface while simultaneously reducing the maintenance and repair costs of pavement. However, there are many disadvantages of mixing the crumb rubber in a dry state, such as the optimum percentage of binder to be used, the mixing methodology adopted, compatibility with bitumen, poor performance, etc.[(9)]. These drawbacks can be overcome by ready-to-use modified bitumen obtained by the wet process method, as the dosage of rubber and compatibility of mixing, blending, etc. will be maintained in the manufacturing plant by the bitumen manufacturer with the help of specialized equipment. The specifications and guidelines issued by the Indian Road Congress (IRC SP-53, 2010) also encourage the use of crumb rubber in pavement construction to achieve the required standards during construction. Available field studies also indicate an improvement in the performance of the pavement with the use of crumb rubber modified bitumen[(10,11)]. In addition, the viscosity and storage stability of the crumb rubber modified bitumen also affect the performance of the bituminous mixes, as the viscosity of the bitumen ensures proper mixing of binder with aggregate, and storage stability is required to maintain homogeneity and easy application[(12)]. However, there is limited research on using crumb rubber modified bitumen by the wet process method on the bituminous mixes and the evaluation of Marshall parameters for these mixes[(13)]. Furthermore, the previous research mainly concentrated on finding the rheological properties of bitumen[(14)] and the performance of the bituminous mixes[(15)] without specifying the specific type of mix to be used for pavement construction in the Indian context. There is limited research on both grades of bituminous mixes using modified bitumen and the recommendations for mix selection. The present research fills the gap by adopting the wet process method and by using conventional and crumb rubber modified bitumen in bituminous mixes, which helps in choosing the grade of bituminous mix (Gr-I or Gr-II), which is commonly used as a surface course layer on all the National Highways (NH), State Highways (SH), and other important roads in India. The investigation was carried out on Bituminous Concrete (BC) Gr-I and Gr-II mixes, and the samples were prepared in the laboratory. Suitable Job Mix Formula (JMF) and Optimum Binder Content (OBC) were found for these mixes. Marshall Stability tests were carried out using both conventional bitumen and modified bitumen at varying percentages of its binder content to measure parameters such as stability, density, air void content, flow, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB).

# 2 Methodology

The common materials used in the research are coarse aggregate, fine aggregate, bitumen, and crumb rubber modified bitumen. The bituminous mixes are prepared by using conventional bitumen and modified bitumen. The materials were obtained from a quarry situated in Bidadi, Bangalore.

## 2.1 Coarse aggregate

The coarse aggregates consist of material passing through 20 mm and retained on a 4.75 mm IS sieve.

## 2.2 Fine Aggregate

The fine aggregates consist of the materials passing through the 4.75 mm sieve and retained on the 0.075 mm IS sieve.

Both coarse aggregate and fine aggregate conform to the standards and specifications outlined in the applicable Indian Standard (IS) code [16].

## 2.3 Bitumen and Modified Bitumen

Conventional bitumen of Viscosity Grade (VG) 30 is used and conforms to the standards and specifications outlined in the applicable Indian Standard (IS) code [17].

Crumb Rubber Modified Bitumen (CRMB) 55 is used and conforms to the standards and specifications outlined in the applicable Indian Standard (IS) code [18,19]. The wet process method is adopted for the present investigation. The aggregate, bitumen, and modified bitumen used in the research are subjected to various tests to determine their suitability in accordance with relevant Indian Standard (IS) / Ministry of Road Transport & Highway (MORT&H) code specifications. A suitable Job Mix formula (JMF) was arrived at for the BC Gr-I and Gr-II mixes based on a trial and error method. Marshall specimens were cast for different percentages of bitumen and crumb rubber modified bitumen content to arrive at optimum binder content.

## 2.4 Marshall method of mix design

The Marshall stability value refers to the maximum load that a compacted specimen can withstand at a standard test temperature of 60°C. The deformation of the specimen is called the flow value. It occurs during the loading of the sample until it reaches a maximum value. During the stability test, flow is measured in terms of 0.25 mm and is observed between the specimen's no-load state and its maximum load state. The test is designed for hot mix designs made of aggregates and bitumen. The maximum aggregate size to be used in the test is 25 mm. The test method is commonly employed in the laboratory for designing and evaluating bituminous paving mixes. Marshall specimens are prepared in the laboratory to meet the standards and specifications as laid in ASTM D 6927for different percentages of binder content. The optimum binder content and various Marshall parameters are measured [20]. However, the Marshall method of mix design may not be suitable for the design of open graded bituminous mixes, and the results are temperature dependent. In addition, it does not consider the effects of environmental conditions and dynamic loading conditions.

# 3 Results and Discussions

## 3.1 Results of coarse and fine aggregate

The coarse and fine aggregates are subjected to basic tests such as specific gravity, water absorption, impact value, abrasion, shape tests, plasticity index, etc., and are shown in Table 1.

**Table 1. Results of Coarse and Fine Aggregate**

| Name of the Test | Results | Reference code as per Indian Standard (IS) | Permissible limit as per MORT&H |
|---|---|---|---|
| Cleanliness (max), % | 2.8 | 2386-Part-I | 5.0 |
| Specific gravity (coarse aggregate) | 2.68 | 2386 Part-III | 2.5-3.0 |
| Specific gravity (fine aggregate) | 2.62 | | |
| Water absorption, % | 0.45 | | 2.0 |
| Aggregate Impact Value (%, max) | 17.53 | 2386 Part-IV | 27.0 |
| Los Angeles Abrasion Value (%, max) | 13.89 | | 35.0 |
| Flakiness and Elongation Index (%, max) | 12.60 | 2386 Part-I | 35.0 |
| Plasticity Index, Fine Aggregate (%, max) | 2.8 | 2720 Part-V | 4.0 |

## 3.2 Results of conventional bitumen and modified bitumen

The VG 30 and CRMB 55 grade bitumen were subjected to basic tests such as specific gravity, penetration, softening point, flash and fire point, ductility, etc., and the results are shown in Table 2.

**Table 2. Results of Conventional Bitumen and Modified Bitumen**

| Name of the Test | VG 30 | | CRMB 55 | | Reference code as per Indian Standard (IS) |
|---|---|---|---|---|---|
| | Results | Permissible limit as per MORT&H | Results | Permissible limit as per MORT&H | |
| Specific Gravity, (min) | 1.01 | – | 1.13 | – | 1203-1978 |
| Penetration test, (mm), min | 62.1 | 45 | 57.5 | <60 | 1203-1978 |
| Softening point, (R&B) °C, (min) | 49 | 47 | 62.1 | 55 | 1203-1978 |
| Flash and Fire point, °C (min) | 275 & 302 | 220 | 278 & 310 | 220 | 1203-1978 |
| Ductility, °C, min at 27$^0$C, min, cm | 81.4 | 75 | 65.50 | —- | 1208-1978 |

## 3.3 Results of Job Mix Formula (JMF) and Optimum Binder Content (OBC)

The Job Mix Formula (JMF) of the bituminous mixes has arrived to match the gradation requirement. The obtained gradation curve for the BC Gr-II mix is shown in Figure 1. The Marshall specimens were cast for different percentages of conventional bitumen and modified bitumen, starting at 5.0%, 5.25%, 5.50%, 5.75%, 6.0%, and 6.25%, respectively, and the Optimum Binder Content (OBC) was found. The values of JMF and OBC are shown in Table 3. The obtained optimum binder content for BC Gr-I bituminous mix with VG 30 bitumen and crumb rubber modified bitumen was 5.50% and 5.30%, respectively. Similarly, for BC Gr-II bituminous mix, it is 5.80% and 5.50%, respectively, and the mix satisfies the minimum requirement as per MORT&H specifications. In addition, it is observed that the binder content in both grades of mixes in the case of crumb rubber modified bitumen is 0.2% and 0.3% less than that of conventional bituminous mixes.

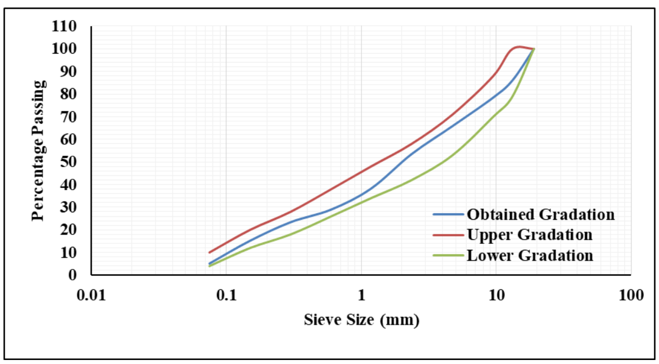


**Fig 1. Gradation Curve for Bituminous Concrete Gr-II Mix**

**Table 3. Results of JMF and OBC for Bituminous Mixes**

| Type of Mix | Aggregate Percentage | | | Optimum Bonder Content (%) | |
|---|---|---|---|---|---|
| | 20 mm and down size | 12.5 mm and down size | 4.75 mm and down size | VG 30 | CRMB 55 |
| BC Gr-I | 25 | 35 | 40 | 5.50 | 5.30 |
| BC Gr-II | 15 | 25 | 60 | 5.80 | 5.50 |

## 3.4 Results of Marshall Stability Test

Again, Marshall specimens were cast for BC Gr-I and Gr-II mixes at optimum binder content, and the Marshall parameters such as flow, density, and volume of air voids were found. The results are shown in Table 4.

From Table 4, it is observed that, in BC Gr-I, the mix prepared with crumb rubber modified bitumen has 8.2% more stability value, and in the case of BC Gr-II mix, it is 20.2% more than the conventional bituminous mix, making the pavement surface

**Table 4. Marshall Properties on the Bituminous Mixes Using VG 30 and CRMB 55**

| Marshall Property | BC Gr-I | | BC Gr-II | |
|---|---|---|---|---|
| | VG 30 | CRMB 55 | VG 30 | CRMB 55 |
| Optimum Binder Content (OBC), % | 5.50 | 5.30 | 5.80 | 5.50 |
| Marshall Stability, (kg) | 1995 | 2160 | 2320 | 2790 |
| Flow value, (mm) | 3.53 | 3.44 | 3.74 | 3.61 |
| Bulk density, (gm/cc) | 2.26 | 2.29 | 2.35 | 2.39 |
| Volume of Air Voids (%) | 3.92 | 3.85 | 3.45 | 3.42 |
| Voids in Mineral aggregate (VMA), % | 15.99 | 14.90 | 15.76 | 14.81 |
| Voids filled with Bitumen (VFB, % | 72.43 | 70.80 | 73.56 | 70.54 |

stronger and more durable. Similarly, the modified bitumen mix has a lower flow value than the conventional bituminous mix. This shows the bituminous mixes prepared with modified bitumen are less susceptible to temperature. On comparing the BC Gr-I and BC Gr-II mixes, the BC Gr-II mix exhibits higher Marshall stability and density values than the BC Gr-I mix. This is due to the fact that BC Gr-I is an open graded mix, the smaller aggregates tend to wedge between the larger ones, increasing the voids in the mix. Whereas BC Gr-II is a dense graded mix that has an excess of smaller aggregates, which fill the voids in the mix, making it denser and stronger. Hence, higher Marshall stability and density values are observed in the BC Gr-II mix than in the BC Gr-I mix. The obtained results align closely with the previous findings obtained by adopting the dry process method. However, the use of the wet process method in the current research investigations also shows additional benefits and achieves higher stability and density values due to the fact that it has better blending, mixing, and compatibility with conventional bitumen, which was lacking in the dry process method. The graphs indicating the percentage of bitumen content vs. stability, volume of voids, density, flow, and VFB for BC Gr-II mix are shown in Figure 2. Other Marshall parameters, such as volume of air voids, VMA, and VFB, satisfy the requirements of MORT&H specifications.

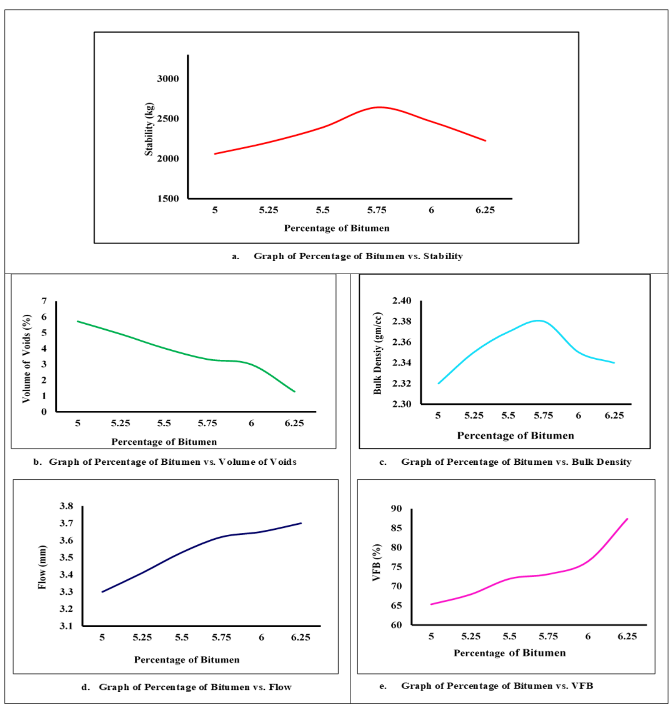


**Fig 2. Graphs of Marshall Properties for Bituminous Concrete Gr-II Mix**

## 4 Conclusions

Based on the experimental investigation, the following conclusions are drawn:

- The optimum binder content in crumb rubber modified bituminous mix in both BC Gr-I and BC Gr-II is 0.2% and 0.3% less than the conventional bituminous mix. This reduces the cost of the construction of the pavement.
- The Marshall Stability value in the case of crumb rubber modified bituminous mix in BC Gr-I is 8.2% higher, and in BC Gr-II, it is 20.2% higher than the conventional bituminous mixes. The results are in line with the earlier research findings, reinforcing the potential benefits of these modifications.
- The crumb rubber modified bituminous mix has a lower flow value than the conventional bituminous mix, making the pavement surface less susceptible to temperature and enhancing durability. This helps in understanding how the modified bituminous can withstand temperature variations and reinforces the idea of using modified bitumen to enhance stability and durability.
- The crumb rubber modified bitumen has a denser mix than the conventional bituminous mixes, making the pavement surface stronger and more durable and emphasizing the enhanced durability and temperature resistance of the modified bituminous mixes.
- Between the BC Gr-I and BC Gr-II mixes, BC Gr-II has higher stability, density, and a lesser flow value, both in the conventional bituminous mix and the modified bituminous mix. This makes it stronger, more durable, and less susceptible to temperature. This finding enables better material selection for particular situations, leading to optimized pavement design and improved road infrastructure.
- Hence, Bituminous Concrete Gr-II is an obvious choice for pavement construction on all the important highways in India. This proposal is based on a thorough understanding of material performance and paves the way for real-world applications.
- The studies also showed viable techniques for improving road functionality, addressing waste disposal problems and environmental issues, and promoting the concept of sustainability in road construction.
- The promising results from the research suggest the scope for cost-effective pavement construction through a reduction in binder content, greatly influencing construction practices.
- Based on the research findings, it is recommended to consider the implementation of the use of modified bitumen in the construction of pavement to achieve enhanced strength, durability, and cost savings.
- To promote sustainability in road construction, it is advisable to explore the innovative techniques for waste disposal and environmental issues, as demonstrated in this study, and integrate these practices into the road construction projects.
- In addition, further research and testing can be done on the long-term performance, strength, durability, and environmental impact of crumb rubber modified bitumen bituminous mixes in various real-world scenarios.

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