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Rutting Performance Evaluation of the Bituminous Mixes using Roller Compactor and Rut Analyzer

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ABSTRACT

The characteristics of the bitumen play a very important role in the performance and durability of flexible pavement. Conventional bitumen has many disadvantages, due to which the pavement undergoes different types of distress, such as cracking, edge breaks, shovelling, rutting, ravelling, heaving, potholes, etc. The performance of the bituminous mixes can be improved by using various types of additives to bitumen, commonly known as modifiers, to obtain modified bitumen. The present investigation is done by conducting Marshall Stability and Rutting tests on a combination of bituminous mixes, namely Bituminous Concrete (BC) Grade-I and Grade- II (Gr-I & Gr-II) used as a surface course layer and Dense Bituminous Macadam (DBM) Grade-II (Gr-II) used as a binder course layer, using both conventional bitumen and Crumb Rubber Modified Bitumen (CRMB). The pavement crust is built as per the specifications of the Indian Road Congress (IRC) 37, 2018. Rutting tests were conducted by indigenously developed equipment, namely the Roller Compactor and Rut Analyzer (RCRA). The results show that the Bituminous Concrete Gr-II mix has 20.1% and 32.4% higher strength than Bituminous Concrete Grade-I mix prepared with conventional bitumen and modified bituminous mixes, respectively. Also, modified bituminous mixes showed higher density and lower flow values than conventional bituminous mixes. The reduced flow values obtained with the modified bituminous mixes make the pavement surface less susceptible to temperature changes. Similarly, the results of rutting tests show the BC Gr-II mix exhibited 38.0% and 50.6% higher resistance to rutting than the BC Gr-I prepared with conventional and modified bituminous mixes, respectively. The findings of the research help in reducing the use of natural resources, reducing the cost of construction, enhancing pavement strength and performance, and simultaneously addressing and reducing the problem of waste disposal.

Keywords:
Bituminous concrete; marshall stability; rutting; crumb rubber modified bitumen (CRMB); roller compactor and rut analyzer (RCRA); pavement performance

1. Introduction

Flexible pavements are the predominant type of pavement commonly used in India and all over the world. During the course of their life span, they are subjected to various types of traffic, loading and overloading, variations in seasonal and climatic conditions, and other severe conditions.

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Research studies conducted on the highways reported that premature failure of the pavement is due to exposure to such severe conditions [1-4]. The common types of failure or distress that are formed on the surface of pavement are cracks, edge breaks, potholes, ravelling, rutting, shoving, slippages, etc. This leads to frequent repairs and resurfacing of the pavement surface, leading to higher maintenance costs and a reduction in pavement life [5]. Rutting may be defined as a longitudinal depression on the pavement surface all along the wheel path of the vehicle. Rutting on the pavement surface sometimes proves to be dangerous, as it may cause the vehicle to skid or topple and lead to accidents. The design of bituminous mixes greatly affects the performance of pavements. The mix design should aim at producing a good quality mix with sufficient bitumen to ensure strength, stability, cohesion, and resistance to shear deformation under heavy traffic loading [6]. Different agencies all over the world use different binders and mix proportions. Bituminous mix parameters such as stability, void ratio, density, voids in mineral aggregate, and voids filled with bitumen affect the performance of the mix [7].

Research studies have demonstrated that the performance of conventional bitumen can be significantly improved by adding chemicals or additives, commonly termed modifiers [8,9]. Some of the commonly used modifiers are waste plastic, polymers, elastomers and crumb rubber, which have been widely used and found to be very effective in improving performance. Many research findings also mention the change in rheological properties of conventional bitumen when these materials are used [10-16]. Previous research studies suggest that in India, about 20% of the waste tyres undergo recycling or retreading, 15% go to various other uses, and the remaining 45% to 50% become part of illegal dumping, landfills, or stockpiles [17]. The disposal of these waste tyres is also causing environmental problems and is a matter of great concern that needs to be addressed as a matter of priority. The use of these waste materials also helps to preserve natural resources, simultaneously reducing the cost of construction of pavement. The crumb rubber is added in a dry process method or in a wet process method, and most of the research has been carried out using the dry process method [18-20]. Crumb rubber modified bitumen has shown a significant impact on rheological properties such as ductility, softening point, viscosity, etc. [21]. Crumb rubber has achieved positive significance because of its advantages, such as reduced pavement thickness, reduction in cost, greater resistance to rutting and deformation, reduced environmental pollution, etc. [22,23]. The Bituminous Concrete (BC) mix is extensively used as a surface course in pavement layers. The primary purpose of the mix is to provide structural support to the pavement layer, distribute traffic loads, and resist the effects of stresses induced by traffic, weathering, and moisture [24]. The BC layer is typically constructed as a single layer of Grade-I or Grade-II. They are designed as per the code provisions to have a rich bitumen mix to sustain fatigue failures, moisture damage, and rutting failures [25,26]. The choice between the two grades depends on the layer thickness and the nominal maximum size of the aggregate. The Marshall Method of Mix Design is commonly adopted for the design of bituminous mixes. The method utilizes optimum material usage and optimum binder content (OBC), resulting in cost-effective pavement mixes [27]. The method stresses the need for stability and strength in the mix to ensure the longevity and durability of the pavement surfaces. In addition, the research studies show that the performance of the bituminous mixes by the dry process is not consistent, as it is influenced by the mixing method, binder grade, rubber size, and aggregate gradation [28,29]. In addition, there is a lack of comprehensive guidelines for the design, and there is very limited research in the laboratory, where the entire pavement crust layer is being constructed and experimentation is carried out.

Hence, there is a need to conduct investigations and assess the performance of crumb rubber modified bitumen by using the wet process method to overcome the disadvantages of the dry process method [30]. The guidelines and specifications of the Indian Road Congress (IRC SP 53, 2010) encourage the use of crumb rubber to achieve the required standards during construction. The layers below the surface course, such as the sub base and base layers, will significantly influence the rutting. The values of the modulus of elasticity (E) value and the poisons' ratio of the materials significantly affect the outcome of the experimental results [31]. Hence, it is essential to construct the entire pavement layer to analyse the pavement's performance against rutting. The present research aims to study the performance of bituminous mixes by wet process method on two different grades of mixes, namely, Bituminous Concrete (BC) Grade-I and Grade-II (Gr-I and Gr-II) by using conventional bitumen and crumb rubber modified bitumen. Marshall specimens were cast in the laboratory based on the suitable Job Mix Formula (JMF), which had arrived by trial-and-error method. Optimum binder content (OBC) was determined for the conventional and modified bituminous mixes, and the various Marshall parameters such as stability, density, flow, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB) were determined. Further, the rutting performance test is carried out by Roller Compactor and Rut Analyzer (RCRA) equipment, which has been specifically designed and fabricated for the present research. The entire pavement crust layer is built so as to meet the standard guidelines and specifications of the Indian Road Congress, IRC-37, 2018, and rutting performance is measured for the bituminous mixes using both conventional and modified bitumen.

2. Methodology

2.1 Materials

The basic materials used in the present research are coarse aggregate, fine aggregate, conventional bitumen, and modified bitumen. Coarse aggregate consists of materials passing a 20 mm sieve and retained on a 4.75 mm Indian Standard (IS) sieve. Fine aggregates consist of material passing through a 4.75 mm sieve and being retained on a 0.075 mm IS sieve. Conventional bitumen of Viscosity Grade (VG) 30 and Crumb Rubber Modified Bitumen (CRMB) 55 were used. The binder course layer, namely, Dense Bituminous Concrete (DBM) Grade-II (Gr-II), and the surface course layer, consisting of two different grades of mixes, namely, Bituminous Concrete (BC) Gr-I and Gr-II, were constructed using both conventional bitumen and modified bitumen.

2.2 Methodology

The methodology followed in the present research is outlined below:

i. The coarse aggregate, fine aggregate, bitumen, and modified bitumen are tested for suitability for use in research by performing basic tests on these materials as per IS or MORT&H [32] standards to ascertain their suitability for use in the research.
ii. Job Mix Formula (JMF) was arrived at by the trial-and-error method to achieve the desired gradation for DBM Gr-II, BC Gr-I, and BC Gr-II mixes.
iii. The Marshall Stability Test is performed in the laboratory on the DBM Gr-II, BC Gr-I, and BC Gr-II mixes to obtain optimum binder content (OBC) and various Marshall parameters such as Stability, Density, Flow, Volume of Air Voids (Vv), Voids in Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB).
iv. The rutting test is carried out in the laboratory using a Roller Compactor and Rut Analyzer (RCRA) equipment on the pavement layer for the combination of the mixes to assess the performance of the BC Gr-I mix and BC Gr-II mix. Two different cases are considered during experimentation. In the first case, the BC Gr-I layer is constructed over the DBM Gr-II layer,

and in the second case, the BC Gr-II layer is constructed over the DBM Gr-II layers. In both cases, a common DBM Gr-II with VG 30 was adopted as a binder course layer.

2.3 Marshall Method of Mix Design

The Marshall method of mix design is commonly adopted to design bituminous mixes in the laboratory. The specimens are prepared in accordance with American Society of Testing Materials (ASTM) D 6927 to determine stability, flow, and optimum binder content (OBC). 1200 gm of coarse aggregate, fine aggregate, dust, and bitumen were taken as per the desired gradation. Aggregates are heated to a temperature in the range of 175^{o}C to 190^{o}C. Bitumen is heated to a temperature in the range of 121^{o}C to 145^{o}C, added to the aggregate, and thoroughly mixed at a temperature range of 154^{o}C to 160^{o}C. The prepared mix was compacted with 75 blows on each side of the specimen at a temperature range of 138^{o}C to 149^{o}C. The specimens are allowed to cool at room temperature for 24 hours. They are carefully extruded from the mould, and their weight, height, and diameter are noted, and corrections are applied if required. The specimens are kept in the water bath for half an hour, maintaining a temperature of 60^{o}C, and thereafter subjected to a Marshall stability test to measure the various parameters. The optimum binder content is obtained with respect to 4% air voids as per the provisions of MORT&H. The procedure is repeated for different percentages of conventional and modified bitumen, ranging from 4.0%, 4.25%, 4.50%, 4.75%, etc., until 6.0%. The cast specimens are shown in Figure 1.

Fig. 1. Marshall specimens at different binder content

2.4 Roller Compactor and Rut Analyzer (RCRA)

The equipment has been specifically developed and fabricated indigenously for the present research and is shown in Figure 2. The different parts of RCRA equipment are as follows:

i. Main Frame: It is made out of steel sections that hold the scissor lift and the platform where the moulds with samples for compacting and rutting are placed.
ii. Scissors Lift: This enables the lifting and lowering of the mould with specimens for compaction and rutting. The proximity sensors that are provided to sense the projection provided in the mould control the raising and lowering.

iii. Mould: These are made of steel plate with a length of 650 mm, a width of 270 mm, and a height ranging from 200 mm to 300 mm. Various heights of mould are employed to attain the desired thickness of pavement layers, as shown in Figure 3.
iv. Hydraulic System: The application of the necessary load or pressure is achieved by the use of a hydraulic pressure system, comprising two electric motors and a hydraulic oil system equipped with control valves.
v. The Loading Frame: The loading frame is rigidly mounted on the main frame and can move to and from for compaction and to simulate wheel movement for rutting measurement.
vi. Rubber Wheel: To conduct rutting tests.
vii. Heating Coil: To heat the bituminous mix kept inside the mould.
viii. Pressure Controllers: To apply and control the load and pressure.
ix. Programmable Logic Control (PLC) Board: To control the entire operation.

Fig. 2. Roller compactor and rut analyzer (RCRA) equipment

Fig. 3. Moulds of RCRA

2.5 Methodology Adopted and Working Principles of RCRA Equipment

The experimental procedure involves the casting of specimens, taking into account the California Bearing Ratio (CBR) and the design traffic of 10 million standard axles (msa) [33]. The thickness of the pavement crust is constructed in accordance with the specifications outlined in Table 1 (IRC 37-2018), and the results of the rutting performance tests are recorded in RCRA. The rutting test is performed in the laboratory on two different cases. In the first case, BC Gr-I is constructed over a Dense Bituminous Macadam (DBM) Gr-II layer, and in the second case, BC Gr-II is constructed over the DBM Gr-II as surface course and binder course layers to evaluate the performance of the mix against rutting.

Table 1
Pavement catalogue for 5% CBR value and 10 msa design traffic

CBR (%)	Traffic load (msa)	Pavement thickness constructed in RCRA (mm)			
		Surface course (BC)	Base/ binder course (DBM)	Base course layer (WMM)	Granular sub base layer (GSB)
5	10	40	80	250	200

The process of preparing the specimen for rutting performance testing involves several steps. The complete pavement structure, including the subbase course layers (Figure 4) and bituminous layers (Figure 5), is constructed according to the specified thickness as outlined in the design. The various layers are compacted using steel rollers in order to attain the desired thickness and density. Once the layer is sufficiently compacted and reaches the desired thickness, it is subjected to a rutting test by applying a load that induces 0.56 MPa (IRC 37, 2018). The application of the load is stopped once the rut depth in the specimen reaches 20 mm (Figure 6). The resulting deformation and number of passes are recorded in the control panel of the equipment (Figure 7). This data can then be transferred to a computer for analysis. The data capture of rutting values is limited to only the surface course layer of the specimen, which is in line with the objectives of the present research. The experiment is conducted on different specimens cast with conventional bitumen and modified bitumen. The different stages of casting and conduction of the experiment and recording of the rutting values in the RCRA equipment are shown in Figure 4 to Figure 7, respectively.

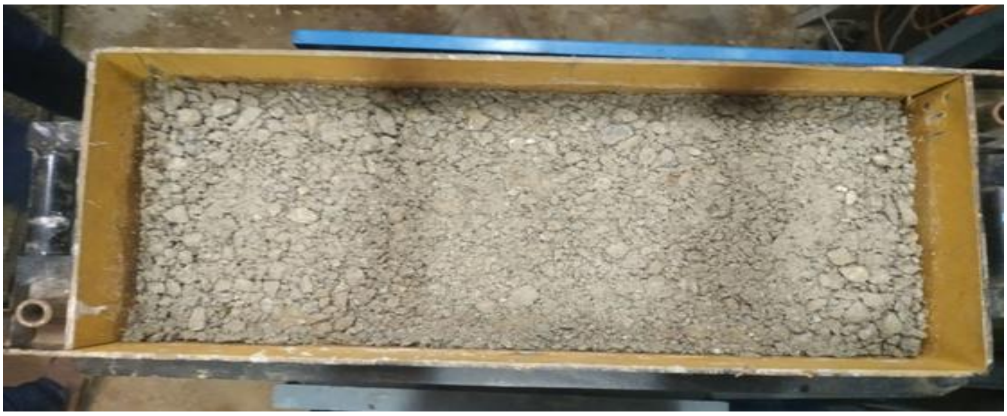

Fig. 4. Casting of base course (WMM) layer

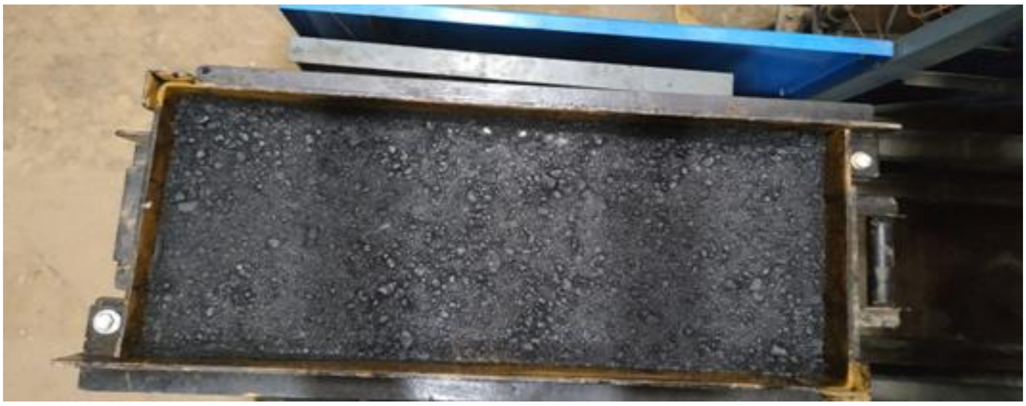

Fig. 5. Casting of bituminous surface course (BC) layer

Fig. 6. Formation of rutting on the surface course (BC) layer

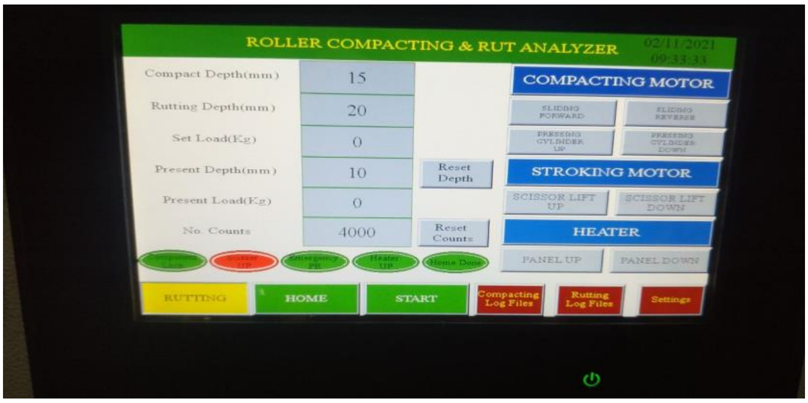

Fig. 7. Display of rutting data in RCRA

3. Results and Discussions

The coarse aggregate, fine aggregate, bitumen, and modified bitumen were tested for their basic properties to check the suitability of these materials to be used in the research. All the materials satisfied the relevant code specification as stipulated by MORT&H. The Job Mix Formula (JMF) is obtained for the BC Gr-I, BC Gr-II, and DBM Grade-II mixes shown in Table 2, and all three mixes satisfied the minimum binder requirement as stipulated by MORT&H.

Table 2
Job Mix Formula (JMF) and optimum binder content (OBC) for bituminous mixes

Type of mix	40 mm & down size aggregate	20 mm & down size aggregate	12.5 mm & down size aggregates	4.75 mm & down size aggregates	Optimum binder content (OBC)	
					VG 30	CRMB 55
DBM Grade-II	15%	20%	28%	37%	4.90%	-----
BC Grade-I	-	30%	30%	40%	5.60%	5.30%
BC Grade-II	--	18%	28%	54%	5.90%	5.50%

The obtained values of the Marshall properties are shown in Table 3. The obtained gradation curves for BC Gr-II and DBM Gr-II are shown in Figures 8 and 9, respectively. The obtained optimum binder content in the case of crumb rubber modified bitumen for BC Gr-I and BC Gr-II mixes are 0.3%

and 0.4% less than conventional bitumen, respectively. The results are in line with the previous research findings.

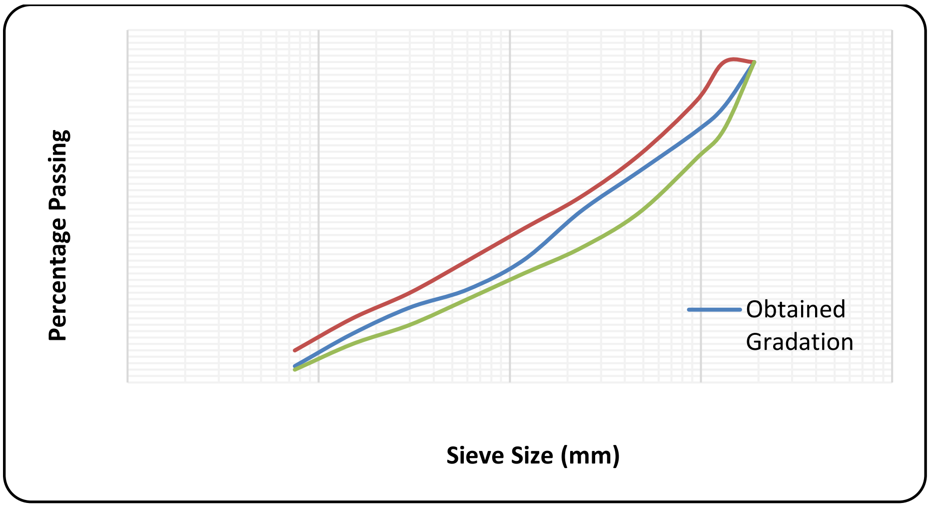

Fig. 8. Gradation curve for BC Gr-II mix

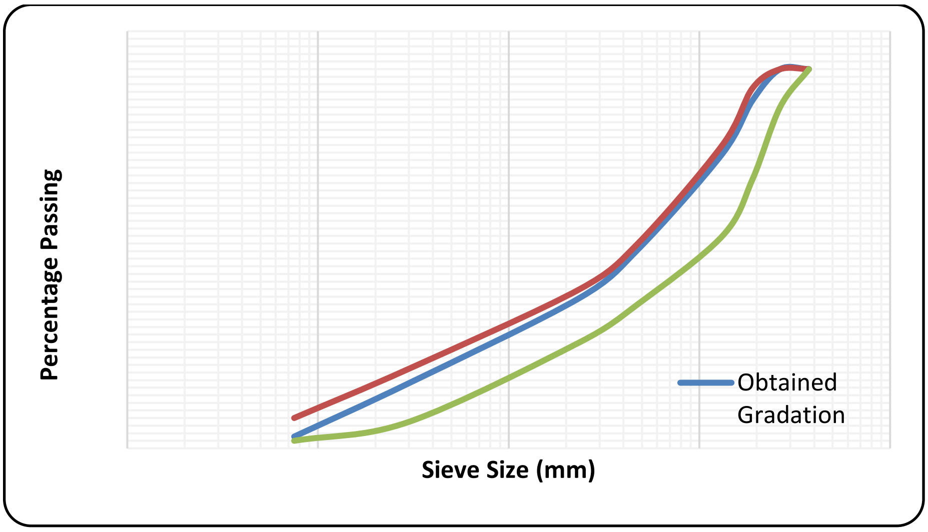

Fig. 9. Gradation curve for DBM Gr-II mix

Table 3
Marshall properties for various bituminous mixes at optimum binder content (OBC)

Marshall properties	DBM Gr-II with VG 30	BC Gr-I With VG 30	BC Gr-I With CRMB 55	BC Gr-II With VG 30	BC Gr-II With CRMB 55
Marshall Stability (Kg)	1210	1990	2220	2390	2940
Flow Value (mm)	3.85	3.65	3.51	3.87	3.70
Bulk Density (g/cc)	2.24	2.28	2.31	2.36	2.39
Volume of Air Voids, Vv (%)	3.90	4.10	3.87	3.55	3.40
Voids in Mineral aggregate, VMA (%)	15.40	16.67	14.66	14.69	13.98
Voids Filled with Bitumen, VFB (%)	69.76	74.56	71.32	73.56	70.54

It is observed from Table 3 that the DBM Gr-II mixes, which is used as the binder course layer of the pavement, satisfies the requirements as stipulated in MORT&H. BC Gr-II has 20.1% and 32.4% higher stability than BC Gr-I, both in conventional and modified bituminous mixes. Similarly, modified bituminous mixes have marginally higher density values than conventional bituminous mixes. In addition, the modified bituminous mix exhibits a lower flow value than conventional bituminous mixes. The reduction in flow value makes the pavement surface less susceptible to temperature and enhances its durability. The other parameters, such as volume of voids, voids in mineral aggregate, and voids filled with bitumen, satisfied the minimum requirements as stipulated by MORT&H.

3.1 Results of Rutting Values in RCRA

The two different combinations of mixes, namely, BC Gr-I with DBG Gr-II and BC Gr-II with DBM Gr-II mixes, constructed as binder course and surface course layers, were subjected to a rutting performance test in RCRA, and the obtained results are shown in Table 4.

Table 4
Rutting test results in RCRA for BC Gr-I and Gr-II mixes

Rut Depth (mm)	Number of Passes in RCRA			
	BC Gr-I With VG 30	BC Gr-I With CRMB 55	BC Gr-II With VG 30	BC Gr-II With CRMB 55
0	0	0	0	0
2	5489	6456	7709	8241
4	10421	11322	13450	15156
6	13556	15598	17109	21234
8	15698	18659	19845	24989
10	17453	21322	22050	27343
12	19335	22869	24107	29305
14	19865	24005	25101	31190
16	20156	26120	27078	34453
18	20985	28004	28956	38768
20	21765	29100	30045	43830

It is observed from Table 4 that the BC Gr-I mix prepared with the modified bitumen sustains 33.70% more rutting than the conventional bituminous mixes for a 20 mm rut depth. Similarly, BC Gr-II mix prepared with modified bitumen sustains 45.88% more rutting than conventional bituminous mix. Among the BC Gr-I and BC Gr-II mixes, the BC Gr-II mix has greater resistance to rutting failure to an extent of 38.0% and 50.6%, respectively, with conventional and modified bituminous mixes. Overall, it is observed that the modified bituminous mix has greater strength, stability, density, and resistance to rutting than conventional bituminous mixes.

4. Conclusions

The following are the conclusions drawn from the research:

i. The optimum binder content (OBC) in the case of crumb rubber modified bituminous mix, both in BC Gr-I and BC Gr-II are 0.3% and 0.4% lower than the conventional bituminous mix, respectively. This contributes to a reduction in pavement construction costs.
ii. Compared to conventional bituminous mixes, the Marshall stability value for bituminous mixes with crumb rubber modified bituminous mix is 11.5% higher in BC Gr-I, and 23.0% higher in BC Gr-II mixes. The results are in line with the earlier research findings, reinforcing the potential benefits of these modifiers.
iii. Between the BC Gr-I and BC Gr-II, the BC Gr-II has 20.1% and 32.4% higher stability than the BC Gr-I mix prepared with conventional and modified bitumen, respectively. In

addition, the BC Gr-II mix has more density and a lower flow value than conventional and modified bituminous mixes. 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.

iv. Similarly, among the BC Gr-I and BC Gr-II mixes, BC Gr-II has 38.0% and 50.6% higher resistance to rutting, respectively, than the BC Gr-I mixes, both in the conventional and modified mixes. This helps in suggesting BC Gr-II mix as the most preferable type of mix for the surface course layer of pavement. This proposal is based on a thorough understanding of material performance and paves the way for real-world applications.

v. The studies also demonstrated feasible methods for enhancing road functionality, resolving environmental and waste disposal problems, and simultaneously promoting the concept of sustainability in road construction.

vi. The research findings indicate the potential for cost-effective pavement construction through a reduction in binder content, thereby significantly influencing construction practices.

vii. Based on the research findings, it is suggested to consider the use of modified bitumen in pavement construction to attain enhanced strength, durability, and cost savings.

viii. To promote sustainability in road construction, it is advisable to investigate innovative techniques for waste disposal and environmental issues, as demonstrated in this study, and to incorporate these practices into road construction projects.

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