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An Experimental Investigation on the Rutting Performance of the Polymer Modified Bituminous (PMB) Mixes

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Abstract Flexible pavements are the most common type of pavement constructed in India and around the world using bitumen or asphalt. The pavement surface undergoes early distress or failure due to the high intensity of traffic, the overloading of vehicles, and significant changes in climatic conditions. The performance of conventional bituminous mixes can be improved by modifying the bitumen with the addition of additives, chemicals, waste materials, polymers, rubber, etc. The present investigation is carried out to assess the performance of the bituminous mixes prepared with conventional bitumen and elastomeric thermoplastic-based polymers, namely, Styrene Butadiene Styrene (SBS), a type of Polymer Modified Bitumen (PMB), by subjecting them to Marshall and rutting tests. The pavement crust is built as per guidelines and specifications of the Indian Road Congress (IRC) 37, 2018. The rutting tests at different temperatures were carried out by indigenously developed equipment, namely the Roller Compactor cum Rut Analyzer (RCRA). The results show that the bituminous mixes prepared with polymer modified bitumen have a higher strength in the range of 16% to 21% than mixes prepared with conventional bitumen. Also, modified bituminous mixes showed higher density and a lower flow value, making the pavement surface less susceptible to temperature. Similarly, the results of rutting tests show the polymer modified bituminous mixes exhibited 11.8%, 20.5%, and 28.4% higher resistance to rutting than the mixes prepared with conventional bituminous mixes at 30ºC, 50ºC, and 70ºC respectively. The findings of the research help to reduce the use of natural resources, reduce the cost of construction, and simultaneously enhance the performance of pavement.

Keywords Flexible Pavement, Polymer Modified Bitumen (PMB), Rutting, Indian Road Congress (IRC) 37-2018, Roller Compactor cum Rut Analyzer (RCRA), Pavement Performance

1. Introduction

Flexible pavements are the most common types of pavements constructed in India and all over the world using bitumen or asphalt. They are subjected to early distress failures due to loading and overloading, variations in climatic conditions, etc. [1]. The many research studies conducted on the highways showed premature failure on the pavement surface [2,3]. The common pavement failures or distresses observed on the pavement surfaces are cracks, edge breaks, rutting, ravelling, potholes, shoving, slippages, etc. [4,5], requiring frequent repair and leading to higher maintenance costs. The occurrence of rutting on the pavement surface is considered undesirable due to its potential to cause skidding and traffic accidents. The performance of the bituminous mixes is significantly influenced by their design procedure, which ensures the necessary strength, stability, cohesion, and resistance to shear deformation [6]. In addition, the performance of the bituminous mixes is significantly affected by various parameters such as stability, void ratio, density, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB) [7].

The factor that causes great concern in India is the very high and low pavement temperatures in some parts of the country. Due to this, the pavement tends to become soft during the summer and brittle during the winter. The properties of conventional bitumen can be modified by using chemicals or additives, commonly termed modifiers and bitumen premixed with these modifiers is termed "Modified Bitumen" [8]. Some of the commonly used modifiers are waste plastic, polymers, crumb rubber [9,10] etc. The research studies have revealed that the use of modified bitumen in road construction significantly improves pavement performance [11,12]. In addition, the use of modified bitumen reduces the cost of construction by extending the time for resurfacing and repair of pavement. Indian Standard (IS) 15462-2004 suggests the different grades of Polymer Modified Bitumen (PMB), namely PMB 120, PMB 70, and PMB 40, according to the penetration value of the bitumen [13]. The choice of grade of bitumen depends on the temperature and climatic conditions of the area [14]. Furthermore, Indian Road Congress (IRC) SP-53, 2010 provides guidelines on the use of modified bitumen in road construction [15].

In the Indian context, it is prevalent to use Dense Bituminous Macadam (DBM) as a binder course and Bituminous Concrete (BC) as a surface or as a top layer of pavement on all the important highways. Typically, the construction of both DBM and BC layers involves the use of single layer DBM Gr-II and BC Gr-II mixes. The bituminous mixes are designed according to the MoRT&H specifications [16], to possess a rich bitumen mix, sustain moisture damage, and fatigue failures, and resist rutting failures [17]. The choice of grade of bitumen to be used depends on layer thickness and the maximum size of the aggregate. The Marshall method of mix design (ASTM D 6927-06) is extensively used for the design of bituminous mixes, which employs optimum material and Optimum Binder Content (OBC) [18], resulting in cost effective pavement. The method emphasizes the importance of strength and stability in the mix, ensuring the longevity and durability of the pavement surfaces. From the previous research findings, it is observed that there are limited rutting performance studies carried out using wheel tracking machines by constructing only the surface layer of pavement [19, 20]. However, the entire pavement thickness is not considered in the performance analysis. This research gap is addressed in the present research studies by constructing the entire pavement crust thickness by considering the surface, base, and subbase layers of the pavement with indigenously developed equipment, namely the Roller Compactor cum Rut Analyzer (RCRA).

The present research looks at the different materials and approaches used to enhance the pavement performance based on the previous research findings and intends to investigate the performance of BC Gr-II mix used as a surface or top layer and DBM Gr-II mix as a binder course layer in pavement construction. The DBM Gr-II mix is made from conventional bitumen of Viscosity Grade 30 (VG-30). The BC Gr-II layer is made up of both conventional and polymer modified bitumen. Marshall specimens were cast in the laboratory according to the Job Mix formula (JMF), obtained by the trial and error method. The Optimum Binder Content (OBC) was determined for both conventional and modified bituminous mixes, and several parameters were evaluated, including stability, density, air voids, flow, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). The obtained results for both the BC-Gr-II and DBM Gr-II mixes were compared with the minimum standards and specifications as specified by the Ministry of Road Transport & Highways (MoRT&H). Further, in order to simulate the actual or in-service pavement temperature, rutting specimens were cast, and the performance of the mix at different temperatures, namely, 30°C, 50°C and 70°C was tested. The rutting test is conducted using indigenously designed and fabricated equipment, namely a Roller Compactor cum Rut Analyzer (RCRA). Rutting performance is evaluated using both conventional and polymer modified bitumen by constructing the entire pavement layer in accordance with the Indian Road Congress, IRC-37, 2018, guidelines and specifications. Overall, the aim is to conduct a thorough investigation, evaluation, performance, and suitability of the bituminous paving mixes while taking into account different temperatures and adhering to the standards and guidelines, thereby contributing to pavement material selection and construction methodologies.

2. Materials and Methods

2.1. Materials

The primary materials used in the present research are coarse aggregate, fine aggregate, conventional bitumen and modified bitumen. Coarse aggregate consists of materials passing 20 mm and retained on a 4.75 mm Indian standard (IS) sieve. Fine aggregates consist of material passing through 4.75 mm and retained on a 0.075 mm IS sieve. Conventional bitumen of Viscosity Grade 30 (VG-30) and two different grades of elastomeric thermoplastic-based polymer, namely, Styrene Butadiene Styrene (SBS) 70 and 40, a type of Polymer Modified Bitumen (PMB), were used. Bituminous mixes consist of Bituminous Concrete (BC) Grade-II used as a surface or top layer of pavement built using the conventional and modified bitumen. The Dense Bituminous Macadam (DBM) Gr-II used as the binder course layer of pavement is built using conventional bitumen of Viscosity Grade 30 (VG-30). All the aforementioned materials complied with the minimum requirements outlined in the applicable code.

2.2. Methodology

The methodology followed in the present research is outlined below:

- Materials such as coarse aggregate, fine aggregate, bitumen, and modified bitumen were tested in the laboratory for their suitability for use in the research.

- Based on the Job Mix Formula (JMF), by adopting the trial-and-error method, suitable gradation for bituminous mixes is obtained.
- The Optimum Binder Content (OBC) for the BC Gr-II, and DBM Gr-II mixes for both conventional bitumen and polymer modified bitumen is found.
- The performance of the bituminous mixes is assessed by conducting a Marshall stability test, and various Marshall parameters are analysed.
- The rutting performance test on the bituminous mixes is carried out by Roller compactor cum Rut analyzer (RCRA) equipment at different temperatures, namely, at 30ºC, 50ºC and 70ºC.

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 following the guidelines outlined in the American Society of Testing Materials (ASTM D 6927) standard in order to assess their stability, flow, and Optimum Binder Content (OBC). A total of 1200 gm of aggregate are mixed suitably as per the obtained gradation. Aggregates are heated to a temperature in the range of 175ºC to 190ºC. Bitumen is heated to a temperature in the range of 121ºC to 145ºC, added to the aggregate, and thoroughly mixed at a temperature range of 154ºC to 160ºC. The prepared mix is subjected to compaction with 75 blows on each side of the specimen, with a temperature range of 138ºC to 149ºC. The specimens are allowed to cool at room temperature for 24 hours. The compacted specimens are carefully extruded from the mould, and their weight, height, and diameter are recorded, and corrections are applied if necessary. The specimens are submerged in the water bath for a duration of 30 minutes, maintaining a temperature of 60ºC. Then they are subjected to the Marshall stability test to measure the various parameters. The optimum binder content is determined to correspond to 4% air voids, as specified by MoRT&H. The procedure is repeated with conventional and polymer modified bitumen at various percentages, starting from 4.0%, 4.25%, 4.50%, 4.75%, etc., until 6.0%.

2.4. Roller Compactor cum Rut Analyzer (RCRA)

The equipment has been indigenously developed and fabricated for the present research, is shown in Figure 1. The different parts of RCRA equipment are as follows:

- **Main Frame:** It is composed of steel sections to carry the scissor lift and the platform where the compacting and rutting samples are placed in the mould.
- **Scissors Lift:** This allows the raising and lowering of the mould containing specimens for compaction and rutting and is controlled by the proximity sensors that detect the projection within the mould.
- **Mould:** They are made of steel plates that are 650 mm long, 270 mm wide, and 200 mm to 300 mm high. As shown in Figure 2, various heights of mould are used to achieve the desirable thickness of pavement layers.
- **Hydraulic System:** The required load or pressure is applied by means of a hydraulic pressure system, which consists of two electric motors and a hydraulic oil system with control valves.
- **The Loading Frame:** The loading frame is rigidly mounted to the main frame and can move to and fro to simulate wheel movement for rutting measurement.
- **Rubber Wheel:** For performing rutting experiments
- **Heating Coil:** To heat the bituminous mixes contained within the mould.
- **Pressure Controllers:** To apply and regulate the pressure and load.
- **Programmable Logic Control (PLC) Board**: To record the rutting values.

2.5. Methodology Adopted and Working Principles of RCRA Equipment

The testing methodology involves the casting of specimens by considering a California Bearing Ratio (CBR) of 10% and a design life of 10 million standard axles (msa). The pavement crust thickness is built in accordance with the parameters mentioned in Table 1 (IRC 37-2018), and the results of the rutting performance tests are recorded in RCRA. The pavement performance is evaluated by conducting the rutting test in the laboratory on BC Gr-II layers using both conventional and modified bitumen, and Dense Bituminous Macadam (DBM) Gr-II is constructed by using conventional bitumen as a binder course layer.

Table 1. Pavement catalogue for 10% CBR value and 10 msa design life

CBR (%)	Traffic Load (msa)	Pavement Thickness Constructed in RCRA (mm)		
		Surface Course	Base/ Binder Course	Wet Mix Macadam (WMM)
5	10	40	80	250

There are different stages in the preparation of the specimens for performance testing. The entire pavement crust thickness is built in accordance with the pavement catalogue as indicated in Table 1, including the subgrade, base course layers (Figure 3), and bituminous layers (Figure 4). To achieve the desired thickness and density, different layers are compacted using the steel rollers. After the desired thickness and compaction have been achieved, the specimen is subjected to a rutting test by applying a load that induces 0.56 MPa (IRC 37, 2018). The load is removed once the rut depth in the specimen reaches 20 mm (Figure 5). The resulting deformation and number of passes are recorded in the control panel of the equipment (Figure 6). The data is then transferred to a computer for analysis. The experiment is carried out on different specimens cast using conventional bitumen and modified bitumen. The different stages of casting, conduction, testing, and recording are shown in Figures 3-6.

Figure 1. Roller Compactor cum Rut Analyzer (RCRA) Equipment

Figure 2. Moulds of RCRA

Figure 3. Sub Base Layer Construction

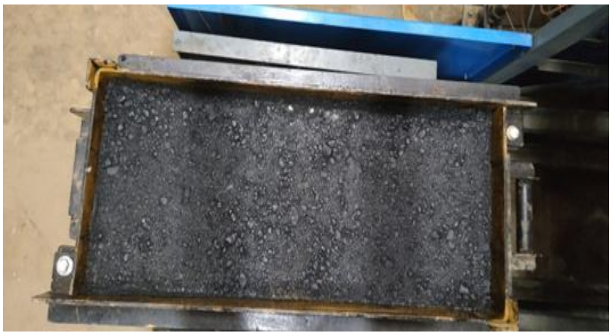


Figure 4. Surface Layer Construction

Figure 5. Specimen subjected to Rutting

Figure 6. Progarmmable Logic Unit (PLC) of RCRA

3. Results and Discussions

3.1. Results of Marshall Test

The coarse aggregate, fine aggregate, bitumen, and modified bitumen were tested for basic properties to ascertain the suitability of these materials as per the MoRT&H specifications. The obtained Job Mix Formula (JMF) for the BC Gr-II mix and DBM Gr-II mixes is shown in Table 2, and both mixes satisfied the minimum binder requirements as per code specifications. The obtained gradation curve for DBM Gr-II is shown in Figure 7. The Optimum Binder Content in PMB 70 and PMB 40 is 0.2% less than that of conventional bitumen. This results in a considerable reduction of the cost of construction on large road projects. The results of the Marshall parameters are shown in Table 3.

There is an increase in the Marshall stability value in the cases of PMB 70 and PMB 40 by 20.30% and 16.9%, respectively. Similarly, the density in both grades of polymer modified bituminous mixes was marginally higher than that of conventional bituminous mixes. In addition, the other parameters such as flow, volume of air void, VMA, and VFB, satisfied the requirements of MoRT&H specifications.

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	PMB 70	PMB 40
DBM Grade-II	12%	23%	30%	35%	4.80%	---	----
BC Grade-II	--	15%	30%	55%	5.80%	5.60%	5.60%

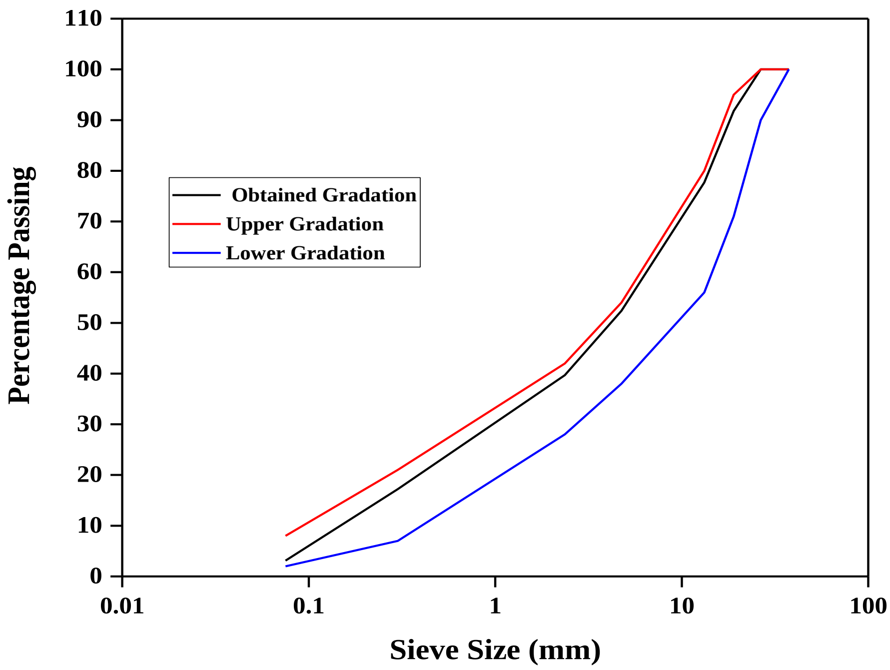


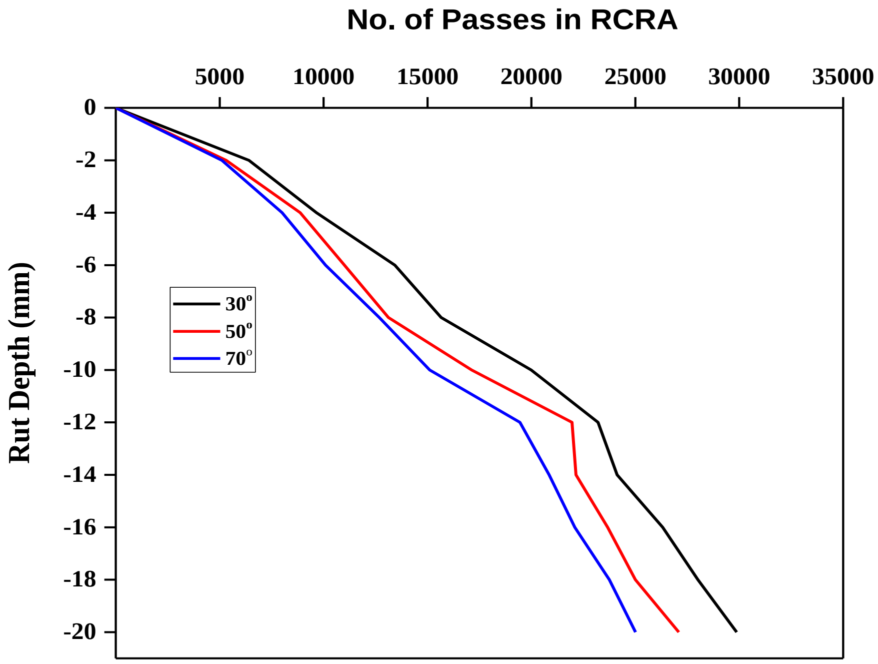
Figure 7. Gradation Curve for DBM Gr-II Mix

Table 3. Marshall Properties for Various Bituminous Mixes at Optimum Binder Content (OBC)

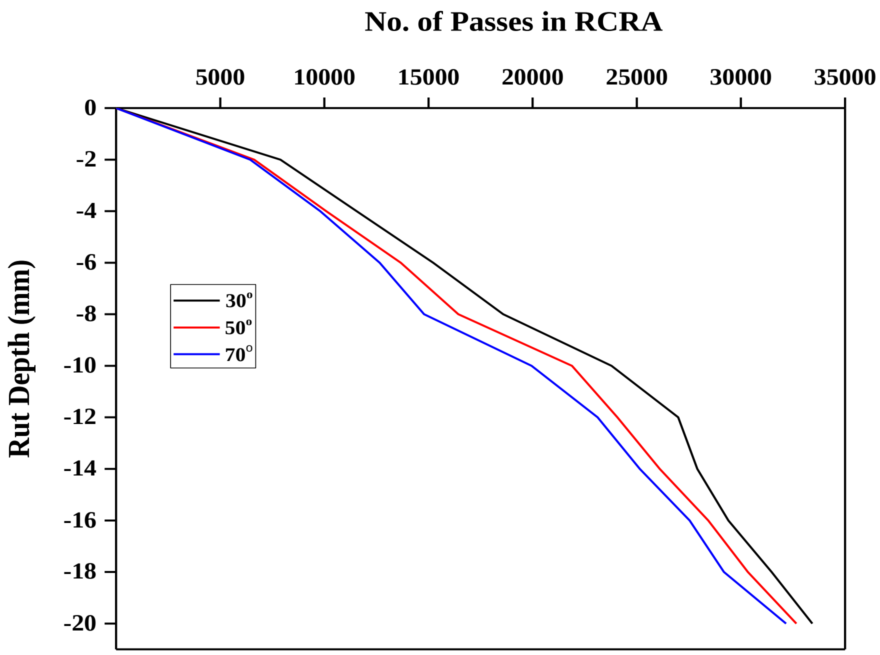
Marshall Properties	DBM Gr-II with VG 30	BC Gr-II		
		VG 30	PMB 70	PMB 40
Marshall Stability, (Kg)	1210	2360	2840	2760
Flow Value, (mm)	3.85	3.65	3.44	3.52
Bulk Density, (g/cc)	2.24	2.34	2.55	2.45
Volume of Air Voids, Vv (%)	3.90	3.65	3.51	3.40
Voids in Mineral Aggregate, VMA (%)	18.90	16.10	17.56	18.89
Voids Filled with Bitumen, VFB (%)	73.65	64.90	71.20	73.60

3.2. Results of Rutting Test in RCRA

The BC Gr-II specimens cast with conventional bitumen and polymer modified bitumen were subjected to rutting performance tests at different temperatures in RCRA, and the obtained results are shown in Table 4. Figure 8 shows the rutting behavior of VG 30, PMB 70, and PMB 40 mixes at different temperatures, namely at 30ºC, 50ºC, and 70ºC.



(a)



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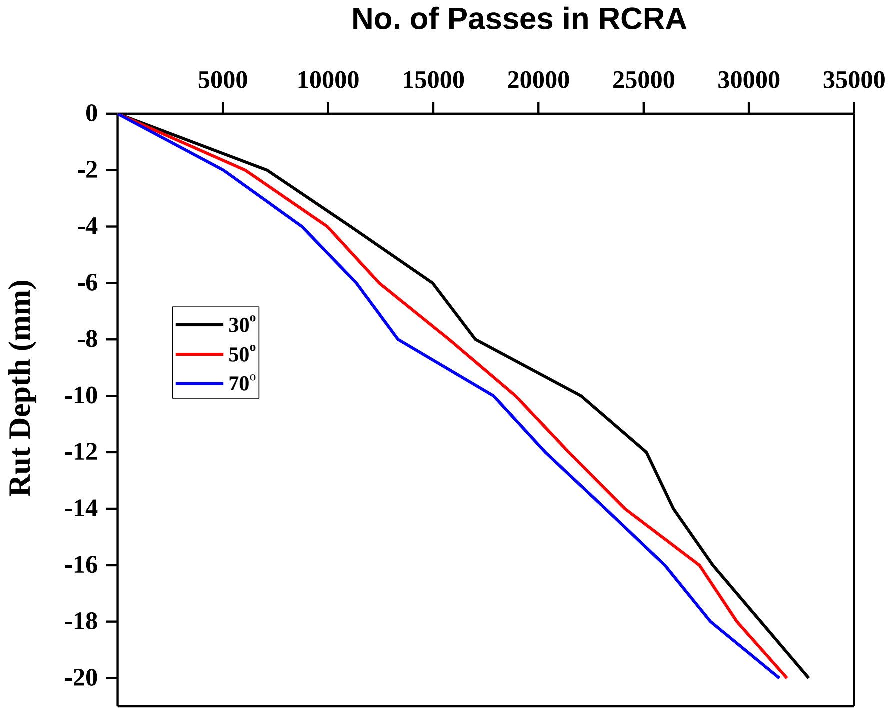

(c)

Figure 8. Graph of Rutting Values for (a) VG-30, (b) PMB 70 (c) PMB 40 mixes at Various Temperatures

Table 4. Rutting Test Results for BC Gr-II mix using Conventional and Polymer Modified Bitumen

Rut Depth (mm)	Number of Passes in RCRA								
	VG 30			PMB 70			PMB 40		
	30ºC	50ºC	70ºC	30ºC	50ºC	70ºC	30ºC	50ºC	70ºC
0	0	0	0	0	0	0	0	0	0
2	6410	5313	5106	7890	6632	6436	7109	6076	5038
4	9656	8876	8004	11549	10087	9802	11076	9965	8765
6	13434	11007	10095	15222	13671	12654	14970	12429	11345
8	15659	13116	12678	18587	16430	14783	17005	15755	13329
10	19987	17123	15106	23786	21887	19950	22023	18909	17870
12	23204	21953	19444	26988	24070	23120	25130	21444	20326
14	24125	22145	20853	27908	26103	25145	26412	24109	23181
16	26320	23665	22090	29400	28430	27540	28289	27650	26005
18	28007	25003	23750	31470	30333	29180	30567	29432	28180
20	29876	27094	25007	33430	32665	32165	32843	31811	31447

It is observed from Table 4 that the specimens prepared with PMB 70 exhibited 11.8%, 20.5%, and 28.4% more resistance to rutting at 30ºC, 50ºC, and 70ºC respectively, for a 20 mm rut depth than the conventional bituminous mixes. Similarly, PMB 40 showed 9.9%, 17.4%, and 25.7% more resistance to rutting. Between PMB 70 and PMB 40, PMB 70 showed more resistance than PMB 40. The results indicate that the polymer modified bitumen exhibits more resistance to rutting at higher temperatures. Overall, it is observed that polymer modified bitumen has greater strength, stability, density, and rutting resistance than conventional bituminous mixes.

In summary, the previous research and the present study employ different materials and methodologies to enhance pavement performance, reduce the cost of construction, and advance sustainability in road construction. They offer a significant perspective on improving bituminous mixes for more durable construction.

4. Conclusions

The following are the conclusions drawn from the research:

- The Optimum Binder Content (OBC) in the case of polymer modified bituminous mixes is 0.2% lower than the conventional bituminous mix. This contributes to a considerable amount in pavement construction costs for large road projects.
- Compared to conventional bituminous mixes, the Marshall stability value in the case of polymer modified bituminous mixes is higher in the range of 16% to 21%. The results are in line with the earlier research findings, reinforcing the potential benefits of these modifiers.
- PMB 70 exhibited 28.4% more resistance to rutting for a critical rut depth of 20 mm at 70^0C, indicating polymer modified bituminous mixes are less susceptible at higher temperatures. This finding enables better material selection for particular situations, leading to optimized pavement design and improved road construction.
- The higher Marshall stability and rutting resistance of the polymer modified bituminous mixes help extend the service life of the pavement. In addition, this extends the time period for resurfacing the pavement, thereby saving a considerable amount of road maintenance costs.
- Based on the research findings, it is suggested to consider the use of polymer modified bitumen in pavement construction to attain enhanced strength, durability, and cost savings.
- The studies also demonstrated feasible methods for enhancing road functionality, resolving environmental problems, and simultaneously promoting the concept of sustainability in road construction.
- To promote sustainability in road construction, it is advisable to investigate innovative techniques to improve road functionality, as demonstrated in this study, and to incorporate these practices into road construction projects.

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