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Effect of Binder Type, Binder Content, Aggregate Gradation, Temperature and Air Voids on Rutting Susceptibility of Bituminous Mixes

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Abstract
This paper presents an experimental investigation carried out to evaluate the rutting susceptibility of bituminous mixes. The effect of binder type and content, aggregate gradation and temperature are evaluated by means of a wheel tracking test. Two conventional VG 30 and VG 40 binders and one SBS polymer modified binder PMB 40 are used. Three types of aggregate gradations for bituminous concrete (BC), a dense graded mix commonly used surface course in the bituminous pavements in India have been considered. Wheel tracking tests are conducted at temperatures of 30, 40, 50 and 60 °C. Test results show that at high temperatures, polymer modified bituminous mixes performed better than the mixes prepared with conventional binders. However, the difference between rutting in mixes prepared with VG 40 and PMB 40 binders was marginal. Mixes with Superpave gradation performed better compared to the mixes with midpoint gradation.

Keywords: aggregate, binder, bituminous mix, gradation, rutting

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INTRODUCTION

Rutting is one of the most common pavement distresses that occur in bituminous pavements. It develops gradually as the number of wheel load applications increases and usually appears as longitudinal depressions in the wheel paths accompanied by small upheavals on the sides. It represents an accumulation of small amounts of unrecoverable deformations under the channelized repeated wheel loads.[1] Densification and shear deformation are the mechanism of rutting. Shear deformation, rather than densification, is considered to be the primary mechanism of rutting in bituminous mixes.[2–4] Rutting may occur in any layer of the pavement structure including subgrade, base and in the bituminous layer itself.[5]

In recent years, the amount and severity of rutting on bituminous pavements in India has been increasing due to the ever increasing traffic volumes, overloading and the high summer temperatures. Pavements with thick bituminous layers are highly susceptible to rutting within the bituminous layers, especially at high pavement temperatures and when subjected to high tire pressures and heavy axle loads.

Bituminous mixes are composed of aggregate, binder and air voids. The ability of mix to resist rutting depends on careful selection of these components. In order to produce bituminous mixes that have adequate resistance to rutting, it is necessary to know the various properties of the component materials that influence the resistance to rutting of bituminous mix. By carefully choosing the types and proportions of component materials, it is possible to minimize rutting in bituminous mixes.

This paper presents the details of the study carried out on mixes using an indigenously developed wheel tracking device to evaluate the effect of the following factors on the rutting susceptibility of bituminous mixes:

1. Binder type
2. Binder content
3. Aggregate gradation
4. Test temperature
5. Air voids

LITERATURE REVIEW

The properties of binder have a significant effect on the rutting resistance of bituminous mixes.[6] Binder type and content are the major factors affecting the rutting resistance of the mix. It is concluded from the laboratory experiments that there exists a critical level of filling the voids by the bitumen binder, beyond which the mix becomes unstable. Excessive bitumen content is the common cause for shear deformation of the mix.[7] It is reported that rutting in dense graded bituminous mixes is directly related to the bitumen content in the mix.[8] It is found that an increase of 0.25% in the binder content beyond optimum binder content resulted in as much as 40% increase in the rutting.[9]

It is found that the addition of polymers and rubber from recycled tires changes the binder properties and improves the resistance of bitumen binders to rutting.[10] It is reported that stiffer asphalt binder would result in high resistance of HMA mixtures to rutting.[11] It is reported that the use of asphalt modified by SBS polymers or of the Shell MG asphalt gives the wearing course better rutting resistance than a pure asphalt of the same penetration class.[12] It is observed that SBS-modified superpave mixes have shown higher rutting resistance compared to the unmodified mixtures.[13]

Aggregate play an important role in the performance of bituminous mixes as they make up about 90–95% by weight and comprises 75–85% of the volume in the total mix.[14] It is concluded that shear resistance of asphalt mixture is strongly related to the aggregate gradation characteristics.[15] It is reported that aggregate gradation characteristics of the coarse aggregates are strongly related to the resistance of bituminous mixes to rutting.[16–22] It is reported that gradation and nominal maximum size aggregate affect the rutting resistance of the mixes.[23] Rao *et al.* suggested modified aggregate gradation for bituminous concrete mixes to overcome the rutting failure on Indian highways.[24] Well balanced and continuous aggregate gradation will provide the greatest permanent deformation resistance for any type and quality of aggregates.[25] Monismith *et al.* recommended dense gradation to mitigate the effects of rutting.[26] It is concluded that aggregate gradation has a significant influence on rutting resistance.[27] It is concluded that majority of the rutting problems can be attributed to aggregate gradation.[28]

Temperature is one of the most important factors that affect the occurrence of rutting.[11,29] The stiffness of bituminous mix varies with temperature due to the rheological behavior of bitumen binder. As the temperature increases, bituminous mix stiffness decreases and therefore rutting resistance decreases. It is observed that loss of stability in the bituminous mixes is substantial at higher temperatures.[30] It is reported that there is a threshold temperature close to the ring and ball softening point temperature of the binder above which the bituminous mixes show susceptibility to rutting.[31] It is found that under high temperature, rutting occurs and develops quickly even if modified binder used.[6] Celauro studied the effect of temperature variation on permanent deformation characteristics of asphalt layers and predicted that 46, 56, 72 and 79% of rutting occurs during summer, when 24, 12, 4 h and hourly temperature variations were considered respectively. It was also shown that 50% of the rutting occurs during summer season, compared to any other season of the year.[32]

There is a strong relationship between in-place air voids and rutting in the bituminous mixes.[24] It is reported that rut depths increased with the increase in air voids.[32] It is concluded that when air void content drops below 2–3%, bitumen binder acts as a lubricant between the aggregates, resulting in reduction of point to point contact.[33] Results from the laboratory experiments indicated that mixes with air void content below 3% increases the rutting propensity.[24] It is concluded that air voids have significant effect on rutting and that rut depth increases with decreasing air voids.[34] It is concluded that more than 3% in-place air void content is needed to reduce the chance of premature rutting in hot mix asphalt.[35]

MATERIALS USED IN THE STUDY

Aggregate

The crushed aggregate for this study were procured from the Shelda quarry in the state of West Bengal, India. Table 1 presents the properties of aggregates.

Table 1. *Physical Properties of Aggregates.*

Material	Parameter tested	Test value	[27] Specifications (%)
Coarse aggregate	Aggregate Impact Value	12.0%	Max 24
	Los Angeles Abrasion Value	17.5%	Max 30
	Elongation Index + Flakiness Index	22.7%	Max 30
	Water Absorption	0.82%	Max 02
	Specific Gravity	2.823	–
Fine aggregate	Specific Gravity	2.848	–
Mineral filler	Specific Gravity	2.927	–

Binders

Two conventional viscosity grade binders, VG 40 and VG 30 and one SBS polymer modified binder, PMB 40 were used in the investigation. All binders were procured from the Shell Bitumen Plant at Uluberia in the state of West Bengal in India. The properties of binders are presented in Table 2.

Aggregate Gradations Adopted

Bituminous concrete (BC) consisting of dense graded material is generally provided in the wearing course for major highways in India. Hence dense aggregate gradations were selected for the present investigation.

Three types of dense aggregate gradations, namely mid-point gradation[36] commonly used in India, Superpave gradation[1] and a modified gradation proposed by[24] were considered. Figure 1 shows the details of the three gradations.

Table 2. *Properties of Binders.*

Sl. no.	Property evaluated	Type of the binder			Standard test method
		VG 30	VG 40	PMB-40	
1	Penetration @ 25 °C, 100 g, 5 s, 1/10 mm	67	34	41	[17]
2	Softening point, °C	46	61	60	[18]
3	Ductility @ 27 °C, cm	85	76	100+	[19]
4	Specific gravity	1.02	1.03	1.02	[16]

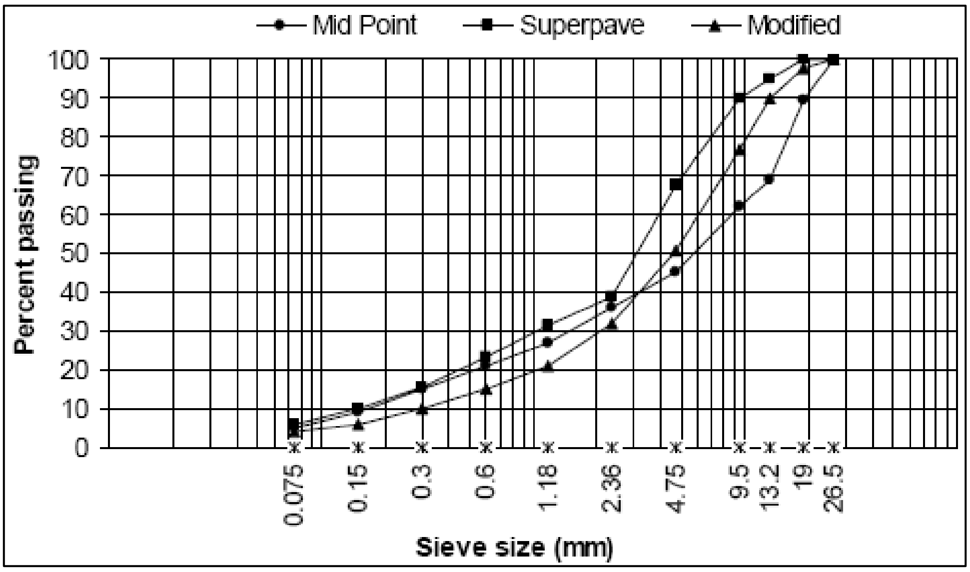

Fig. 1. *Aggregate Gradations Adopted.*

LABORATORY RUTTING TESTS

Laboratory rutting tests on bituminous mixes were conducted using the IITKGP Rut Tester, an indigenously developed wheel tracking tester by the Transportation Engineering Section of IIT Kharagpur. Figure 2 presents the view of IIT KGP Rut Tester.

Fig. 2. *A View of IITKGP Rut Tester.*

The salient features of IITKGP Rut Tester are

1. It is a multi-functional wheel tracking device useful for evaluating the rutting, stripping and moisture susceptibility of bituminous mixes
2. The wheel load is regulated by load cell and can be applied up to 500 kg
3. Capable of varying the test temperature from ambient to 70 °C
4. Arrangement for inducing the water for evaluating stripping and moisture susceptibility of bituminous mixes.
5. Facility to test slab (300 mm × 300/200 mm × 75 mm) or cylindrical samples (laboratory prepared samples using Superpave gyratory, Marshall and vibratory compacted specimens as well as field cores)
6. The conventional flexible pavement can also be simulated
7. Facility to test the specimens in dry or wet conditions
8. Facility to test the specimens up to 20,000 load cycles
9. Data acquisition using data acquisition software and personal computer
10. Facility to operate the equipment both in manual and automated modes
11. Easy to operate and maintain

In the present study, wheel load of 100 kg was applied for all the tests. Tests were conducted at different temperatures of 30, 40, 50 and 60 °C.

Tests were conducted for 5000 wheel load cycles. One load cycle means to and fro movement of the loaded wheel on test sample. Rut depths in bituminous mixes were measured after 5000 cycles.

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Effect of Binder Type on Rutting Resistance of Bituminous Mixes

Bituminous concrete mixes were prepared with midpoint gradation and three types of binders. Binder content of all the mixes was 5% by weight of the total mix. Three samples were prepared at 4% air voids content. Figure 2 shows the variation of rutting susceptibility of bituminous concrete mixes with different binders. It can be observed from the data presented in Figure 3 that the mixes prepared with PMB 40 binder had lower rutting compared to the mixes prepared with conventional binders.

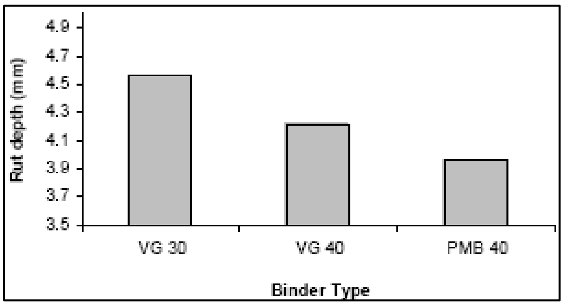

Fig. 3. *Effect of Binder Type on Rutting Susceptibility of BC Mixes.*

Effect of Binder Content on Rutting Resistance of Bituminous Mixes

Five levels of binder contents, 4.0–6.0% with 0.5% increment, by weight of the total mix were considered to evaluate the effect of binder content on rutting susceptibility of bituminous mixes. Mixes were prepared with midpoint gradation and VG 30 binder. Rutting test results with different binder contents are shown in Figure 4.

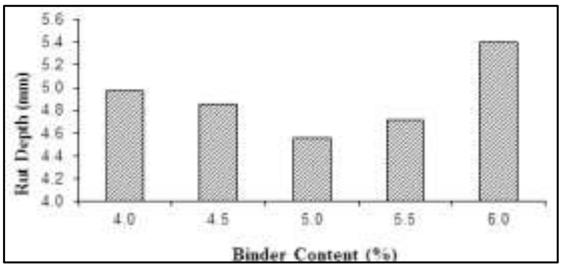

Fig. 4. *Effect of Binder Content on Rutting Susceptibility of BC Mixes.*

It can be observed from Figure 4 that the rutting susceptibility of bituminous concrete mixes varies with binder content. Rutting in the mixes decreased with increase in binder content up to 5% and after this binder content, rutting increased. This is because air voids decreased with increase in binder content up to 5%, as the optimum binder content of the mix is 5.1%. Air voids in the mixes are less than 3% for 5.5 and 6% binder contents and this resulted in higher rutting due to shear deformation.

Effect of Aggregate Gradation on Rutting Resistance of Bituminous Mixes

Bituminous concrete mixes were prepared with the three types of aggregate gradations and VG 30 binder. Mixes were prepared with 5% binder content by weight of the total mix. Rutting test results with different aggregate gradations are shown in Figure 5. It can be observed that the aggregate gradation affects rutting susceptibility of bituminous mixes. The Superpave (SP) gradation has shown lower rutting value compared to mid-point (MP) and modified (MF) gradations. The midpoint (MP) gradation has shown higher rutting value for bituminous concrete mixes.

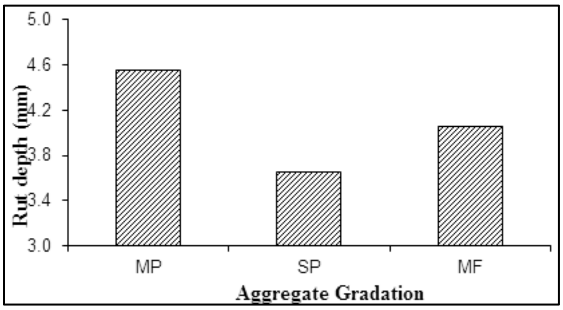

Fig. 5. *Effect of Aggregate Gradation on Rutting Susceptibility of BC Mixes.*

Effect of Temperature on Rutting Resistance of Bituminous Mixes

The bituminous concrete mixes prepared with midpoint gradation and VG 30 binder were tested at different temperatures to evaluate the effect of temperature on the rutting susceptibility of mixes. Tests were also conducted at temperatures of 30, 40, 50 °C. Results of the rutting tests at different temperatures are shown in Figure 6. From the Figure 6, it is observed that with increase in temperature, rutting value of bituminous mixes increased as expected. Rutting in bituminous mixes increased considerably at higher temperatures, especially at 60 °C.

Effect of Air Voids on Rutting Resistance of Bituminous Mixes

Air voids content is one of the most important volumetric parameters of the mixes that affect the performance of the bituminous mixes. Figure 7 shows the variation of rutting in bituminous concrete mixes with different void contents. It can be observed that with the increase in air void content, rutting in bituminous concrete mix increased.

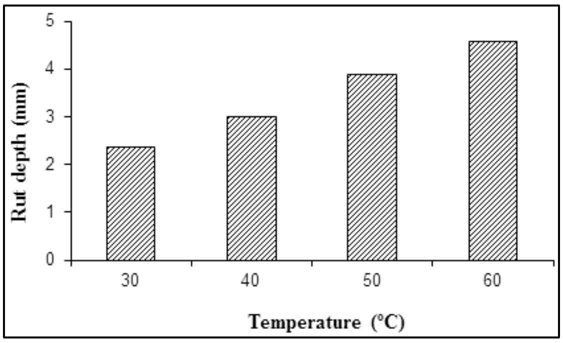

Fig. 6. *Effect of Temperature on Rutting Susceptibility of BC Mixes.*

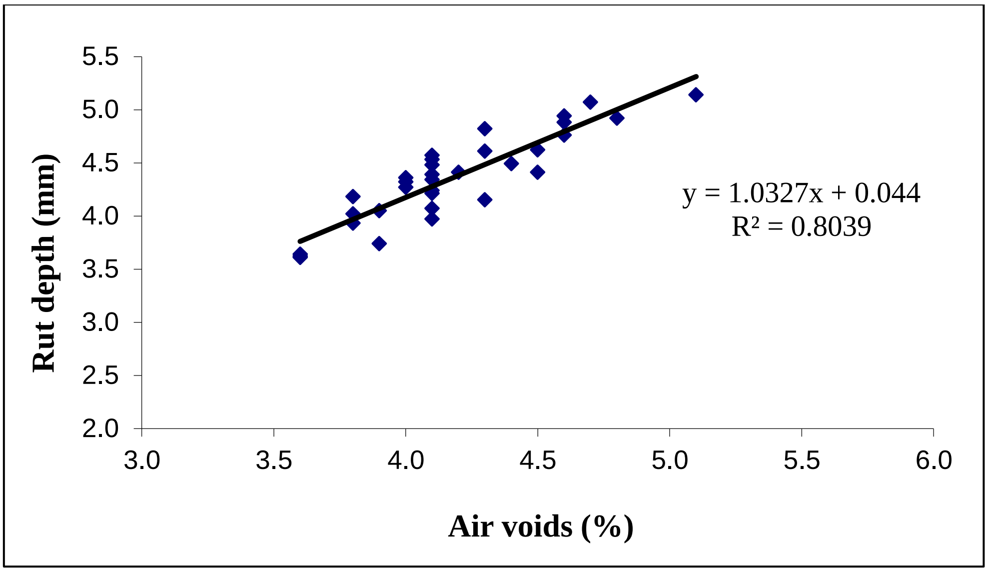

Fig. 7. *Effect of Air Voids on Rutting Susceptibility of BC Mixes.*

CONCLUSIONS

1. Among the three binder types, mixes prepared with PMB 40 binder had higher rutting resistance. However, the difference between rutting in mixes prepared with VG 40 and PMB 40 binders was marginal. This illustrates that these binders can be used in plains of India where maximum air temperature exceeds 40 °C.
2. Rutting tests conducted on mixes prepared with different contents of VG 30 binder yielded lowest rut depth at optimum binder content of 5%. Low binder content leaves more air voids and high binder content fills the voids and acts as lubricant. Therefore in both cases, rutting values are more.
3. Rutting susceptibility increased with increase in the temperature as expected. At 60 °C temperature rutting observed in the mix is almost double that of rutting at 30 °C. This indicates the strong influence of temperature on the performance of the bituminous mix.

4. Mixes prepared with Superpave gradation performed better compared to the mixes prepared with midpoint gradation.
5. Rut depth was observed to increase with air void content. Thus air voids content can be considered as an important volumetric property affecting the performance of the bituminous mixes. Air void content in the mix needs to be controlled for better performance.

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