INFLUENCE OF MIX PROPERTIES ON THE PERMANENT DEFORMATION CHARACTERISTICS OF BITUMINOUS MIXTURES

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Abstract

India is one of the countries having the largest road network where majority of the roads are paved with bitumen-based macadamized roads with a thin bituminous surfacing or a premix carpet as a wearing course. Bituminous roads are mainly composed of naturally available aggregates and hot bitumen/asphalt. In these bituminous pavements Permanent deformation is one of the main failure modes in pavement structures subjected to mechanical loading. Load acting by the vehicle wheel on the pavement of a road result in permanent deformation. Permanent deformations, primarily in the form of ruts in the form of corrugations, tracks, imprints, and shoving are one of the basic asphalt pavement damages impairing its service properties. Ruts may cause vehicles to skid during rains in that case they are more dangerous than the listed above. So as to increase the pavement performance there is a need to increase the quality of pavement in the present study an attempt has been made to evaluate the permanent deformation characteristics of a bitumen mixture with different mix proportions. Wheel tracking testing equipment used to evaluate the rutting performance of bituminous mixtures. By the data of wheel tracking testing can identify the pavement performance and to improve the quality of a road. By developing a model can understand the performance of VG30 bitumen under different temperature conditions.

Keywords: *Permanent Deformation, Bituminous Mix Influence, Rutting Characteristics, Rutting Model By Regression Analysis Etc...*

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1. INTRODUCTION

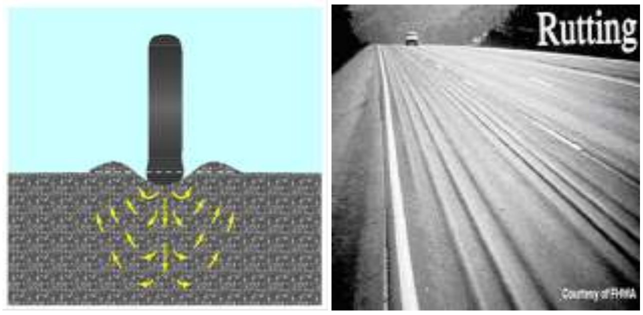
Bituminous mixes have been exposed to greater stresses because of the increasing traffic volumes, higher axle loads than the allowable loads and high type pressures. These increasing stresses pose different forms of failures like fatigue, permanent deformation and surface wear in the early years of the pavement service life. One of the most important forms of distress is the permanent deformation along the wheel paths of bituminous layers which may influence the steering of vehicles at high speeds and hydroplaning.

The basic constituents of bituminous mixes are binder, air voids and aggregates. These three constituents separately or together can affect the rutting in bituminous layers. Aggregate occupy 90 percentages of the volume in bituminous mixes and their shape and texture will influence the aggregate interlocking. Stiffness of the binder plays a major role in rutting and low viscosity binder produces less stiff binder. Air voids in mix can be controlled by compaction during construction of pavements. The mixes having lesser air voids undergo shear failure.

As truck speeds are decreased on a Hot Mix Asphalt pavement, the increase of stresses is because of longer contact times with the pavement. The increase in stresses increases the rutting probability. Higher tyre pressures create higher stresses in the pavement.

1.1 Rutting or Permanent Deformation

Permanent deformation is one of the most important distresses in asphalt pavements in that permanent deformation Rutting is one of the most important form. In now a day the truck loading condition is increases Deformation in the form of rutting in flexible pavement has become the dominant mode of failure. In general rutting has been classified in to three causes in asphalt pavements: sub-grade permanent deformation, accumulation of permanent deformation in the asphalt surfacing layer, and wear of pavements caused by studded tires. Rutting can caused by all of three acts listed above in combination, mean the summation of deformation in all layers of pavement and wear from studded tires.



2. METHODOLOGY

This study concerned to know the changes in rut depth in asphalt pavement by varying test conditions like temperature, air voids, binder types, type of binder grade and binder content. In methodology a detailed review regarding the influence of mix proportions on permanent deformation in asphalt mixtures are discussed.

The methodology divided into two stages: experimental work and analytical work. Mixes like bituminous concrete (BC), dense bituminous concrete (DBM) were prepared by varying the type of binder, binder content, air voids gradation of BC and DBM is used in this study. Mixes were prepared using ASTM D 6926-10: The slabs are prepared by compacting the mixes using roller compactor. The asphalt mixes were tested for rutting at various temperatures (40, 50, 60, and 70 ^{o}C) and at standard load. The rut depth under these conditions is determined using Wheel Tracking Test (WTT) which was developed by British National Rail Road Institute (BNRRI). The performance of mixes is observed by varying test temperatures, type of binder, and binder content.

This study can help to find the correlation of mix properties with permanent deformation in asphalt mixtures. After correlation of the properties, a new model is developed. The performance of asphalt mixes is to evaluated by predicting the rut depth using obtained model.

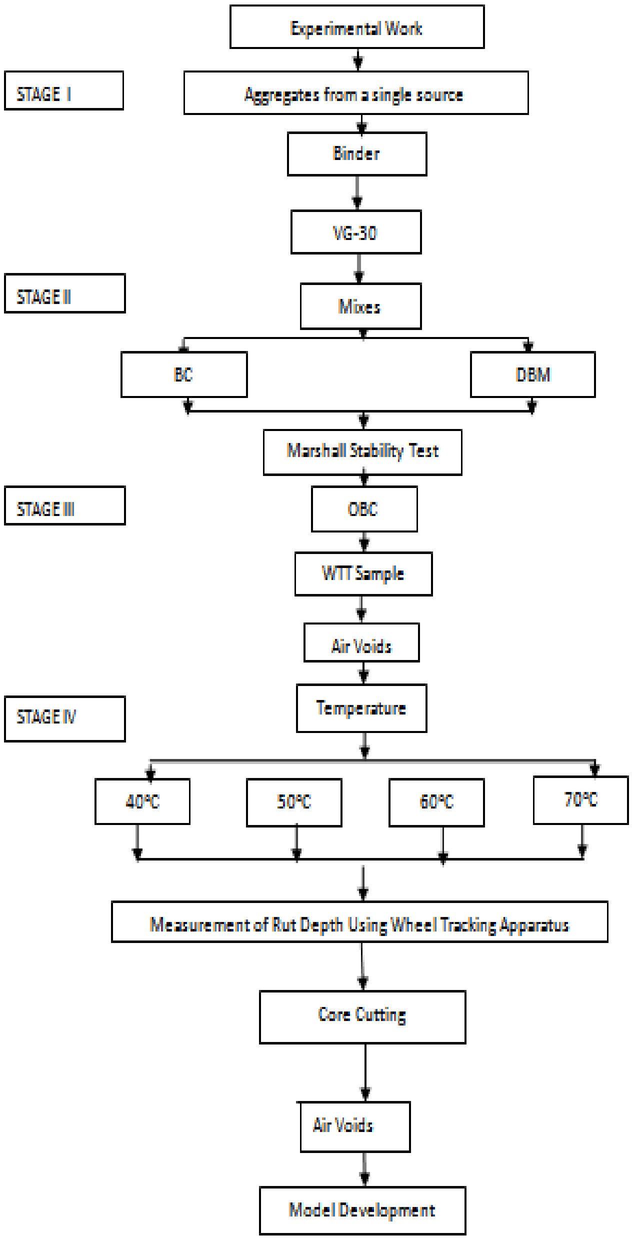


Fig 2 Flow Chat of Methodology

3. LABORATORY INVESTIGATIONS AND DATA ANALYSIS GENERAL

3.1 General

In this chapter details regarding laboratory investigations made for all the materials on isolation as well as a mix along with the analysis have been presented.

3.2 Aggregates

Aggregates are a component of asphalt concrete where in the aggregate acts like reinforcement to the overall composite material strength. The entire aggregate used in this study is from a single source. The aggregates physical properties are tabulated in Table 3.1.

Table 3.2 Aggregate Physical properties

Sl. No	Property	Obtained Value	Specifications
1	Combined Elongation and Flakiness Index	27	30 max
2	Los Angeles Abrasion Value	28	30 max
3	Aggregate Impact Test	20	30 max
4	Specific Gravity Test	2.58	2.5-3
5	Water Absorption	0.1	2 max
6	Stripping Value	95	95 min

3.3 Asphalt Binder

The tests to assess the properties and requirements of paving grade asphalt are the viscosity tests, softening point test, ductility test and the penetration test. Also specific gravity test and flash and fire point tests are needed for use in paving applications. The properties of binders (VG-30) used in this experimentation are listed in Table 3.2.

Table 3.3 Conventional test results of asphalt binders

Sl. No	Property	Values obtained	Specifications
		VG-30	VG-30
1	Penetration at 25 ˚C, 0.1mm (Pen25)	67	50-70
2	Softening Point (R & B), ˚C (SPR&B)	54	47, Min
3	Ductility (cm)	50	70
3	Elastic Recovery at 15 ˚C, %	48	40, Min
4	Flash Point (open cup), ˚C	210	220

3.4 Marshall Stability Test

The values obtained from Marshall Stability Test are discussed below

3.4.1 Bituminous Concrete Mix using VG-30 binder

Marshall Stability test was conducted on BC mix using VG-30 binder and the results are displayed in the table 3.3.1 The Optimum Binder Content (OBC) is found to be 6%.

3.4.2 Dense Bituminous Macadam Mix using VG-30 Binder

Marshall Stability test was conducted on DBM mix using VG-30 binder and the results are displayed in the table 3.3.2 The Optimum Binder Content (OBC) is found to be 5.75%.

Table 3.4.1 Marshall Stability results for BC mix using VG-30

Bitumen (%)	Weight of the Sample		Bulk Specific Gravity (G_b)	% Air Voids (V_a)	VMA	VFB	Marshall Stability (kg)	Flow (mm)
	Air	Water						
5	1188	692	2.25	5.32	18.62	85.47	2388	4.21
5.5	1176	680	2.29	4.27	17.95	90.7	1891	3.24
6	1188	670	2.27	2.5	18.25	79.63	1982	3.12
6.5	1190	678	2.25	1.78	18.36	88.98	2184	4.51
7	1184	686	2.3	2.16	17.22	82.86	2312	4.62

Table 3.4.2 Marshall Stability results for DBM mix using VG-30

Bitumen (%)	Weight of the Sample		Bulk Specific Gravity (G_b)	% Air Voids (V_a)	VMA	VFB	Marshall Stability (kg)	Flow (mm)
	Air	Water						
5	1186	658	2.25	6.06	17.29	64.95	1967	3.26
5.5	1178	650	2.27	4.54	16.48	72.43	1815	2.93
6	1180	656	2.25	5.13	17.52	70.70	2042	2.76
6.5	1174	652	2.25	4.91	17.84	72.49	1891	3.51
7	1190	666	2.27	3.63	17.26	78.95	1922	3.85

3.5 Wheel Tracking Test (WTT)

Wheel tracking test developed by British National Rail Road Institute (BNRRI) used to study the rut characteristics of different HMA pavements and the rut depth characteristics of different sub grade materials. The wheel tracking test setup is as shown in Figure3.5. By this test can measure the rut depth and number of passes to failure. Slabs have been prepared with several combinations to determine the effect of binder type (VG-30), effect of binder content (OBC) used to prepare the mix, mix type (BC, DBM) and effect of temperature (40, 50, 60, and 70 ˚C). The test matrix of the slabs taken with various combinations is given in Table 3.5

Fig 3.5 Wheel tracking testing machine

Table 3.5 Test matrix considered in experimental work

Sample No	mix	Grading	Binder Type	OBC (%)	Temperature	Compaction Duration(min)
1	BC	2	VG-30	6	40	5
2	BC	2	VG-30	6	50	5
3	BC	2	VG-30	6	60	5
4	BC	2	VG-30	6	70	5
5	BC	2	VG-30	6	40	10
6	BC	2	VG-30	6	50	10
7	BC	2	VG-30	6	60	10
8	BC	2	VG-30	6	70	10
9	BC	2	VG-30	6	40	15
10	BC	2	VG-30	6	50	15
11	BC	2	VG-30	6	60	15
12	DBM	2	VG-30	6	70	15
13	DBM	2	VG-30	5.75	40	5
14	DBM	2	VG-30	5.75	50	5
15	DBM	2	VG-30	5.75	60	5
16	DBM	2	VG-30	5.75	70	5
17	DBM	2	VG-30	5.75	40	10
18	DBM	2	VG-30	5.75	50	10
19	DBM	2	VG-30	5.75	60	10
20	DBM	2	VG-30	5.75	70	10
21	DBM	2	VG-30	5.75	40	15
22	DBM	2	VG-30	5.75	50	15
23	DBM	2	VG-30	5.75	60	15
24	DBM	2	VG-30	5.75	70	15

After the WTT, cores were extracted from the samples to know the air voids. Four cores had been cut from the slabs. Using the OBC obtained from the Marshall Stability test wheel tracking samples were casted and tested. The permanent deformation occurred after 30,000 repetitions ($RD_{30,000}$) was measured. $RD_{30,000}$ is used to compare the performance of the BC and DBM mixes tested at different temperatures (40, 50, 60, and 70 ˚C) and with binder type VG-30. Using the rutting performance parameter ($RD_{30,000}$), the effect of temperature and air voids are investigated.

A sample table to know the permanent deformation values after every 200 passes for BC mix prepared using VG-30 and tested at 60 ˚C is shown in Table 3.6

Table 3.6 Rut depths as a function of Number of passes for BC prepared using VG-30 binder

No. of Passes	Rut Depth	No. of Passes	Rut Depth
0	0	15800	3.3193
200	0.2127	14600	3.2415
400	0.2976	14800	3.2571
600	0.3401	15000	3.2843
800	0.3826	15200	3.2999
1000	0.4252	15400	3.3038
1200	0.5102	15600	3.3154
1400	0.6378	15800	3.3193
1600	0.7654	16000	3.3232
1800	0.8929	16200	3.3232
2000	1.0205	16400	3.3349
2200	1.0630	16600	3.3427
2400	1.1481	16800	3.3505
2600	1.1906	17000	3.3544
2800	1.2331	17200	3.3582
3000	1.2757	17400	3.3621
3200	1.3607	17600	3.3699
3400	1.4456	17800	3.3971
3600	1.4882	18000	3.4010
3800	1.5732	18200	3.4166
4000	1.6583	18400	3.4283
4200	1.7008	18600	3.4361
4400	1.7434	18800	3.4477
4600	1.7859	19000	3.4516
4800	1.8284	19200	3.4672
5000	1.9135	19400	3.4711
5200	1.9984	19600	3.4788
5400	2.0835	19800	3.4827
5600	2.1260	20000	3.4983
5800	2.2111	20200	3.5022
6000	2.3387	20400	3.5139
6200	2.3502	20600	3.5255
6400	2.3812	20800	3.5333
6600	2.4237	21000	3.5411
6800	2.5088	21200	3.5528
7000	2.6362	21400	3.5683
7200	2.6788	21600	3.5761
7400	2.6974	21800	3.5839
7600	2.7194	22000	3.5956
7800	2.7213	22200	3.6033
8000	2.7229	22400	3.6189
8200	2.7421	22600	3.6267
8400	2.7638	22800	3.6345
8600	2.7734	23000	3.6461
8800	2.7953	23200	3.6539
9000	2.8063	23400	3.6695
9200	2.8184	23600	3.6734
9400	2.8283	23800	3.6850
9600	2.8489	24000	3.7084
9800	2.8588	24200	3.7123
10000	2.8832	24400	3.7278
10200	2.8917	24600	3.7356
10400	2.9059	24800	3.7434
10600	2.9339	25000	3.7590

10800	2.9503	25200	3.7667
11000	2.9583	25400	3.7784
11200	2.9765	25600	3.7823
11400	2.9831	25800	3.7979
11600	2.9913	26000	3.8173
11800	3.0106	26200	3.8212
12000	3.0190	26400	3.8329
12200	3.0309	26600	3.8484
12400	3.0371	26800	3.8523
12600	3.0615	27000	3.8679
12800	3.0805	27200	3.8718
13000	3.0917	27400	3.8834
13200	3.1015	27600	3.8951
13400	3.1170	27800	3.9029
13600	3.1598	28000	3.9146
13800	3.1715	28200	3.9224
14000	3.1948	28400	3.9340
14200	3.2182	28600	3.9418
14400	3.2260	28800	3.9590
14600	3.2415	29000	3.9629
14800	3.2571	29200	3.9707
15000	3.2843	29400	3.9846
15200	3.2999	29600	4.0076
15400	3.3038	29800	4.0158
15600	3.3154	30000	4.0254

Similar procedure is adopted for all the other 23 specimens and graphs are plotted for rut depth against number of observe to know the three permanent deformation response.

3.5.1 Bituminous Concrete Mix using VG-30 Binder Tested at 40°C

Figure 3.5.1 shows the graph plotted between the rut depth in mm and the number of repetitions for BC mix prepared with 6 % VG-30 binder and compacted for 5 minutes. WTT was carried out at 40 ˚C for this mix. This sample refers to 1st, 9th sample in the test matrix. The rut depth after 30,000 repetitions ($RD_{30,000}$) is 5.48569 mm.

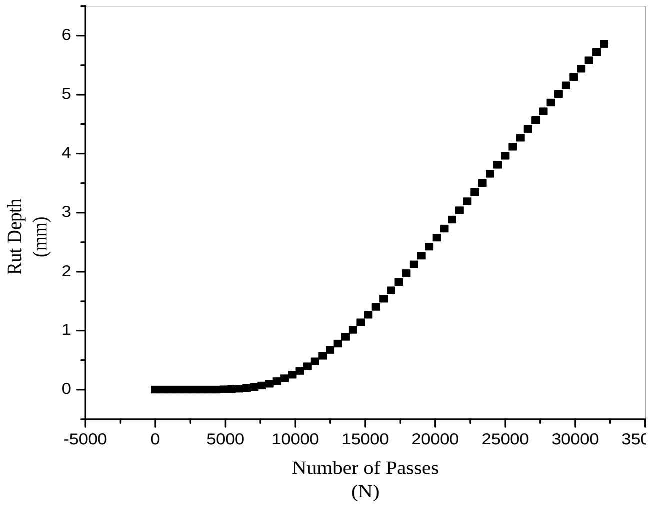


Fig 3.5.1 Rut depth as a function of number of passes for BC using VG-30 binder at 40°C

3.5.2 Dense Bituminous Macadam mix using VG-30 tested at 40°C

Figure 3.5.2 shows the graph plotted between the rut depth in mm and the number of repetitions for DBM mix prepared with 5.75 % VG-30 binder and 5 minutes compaction. WTT is carried out at 40 ˚C for this mix. This sample refers to thirteenth sample in the test matrix given in Table 3.7. The rut depth after 30,000 repetitions ($RD_{30,000}$) is 5.99762 mm.

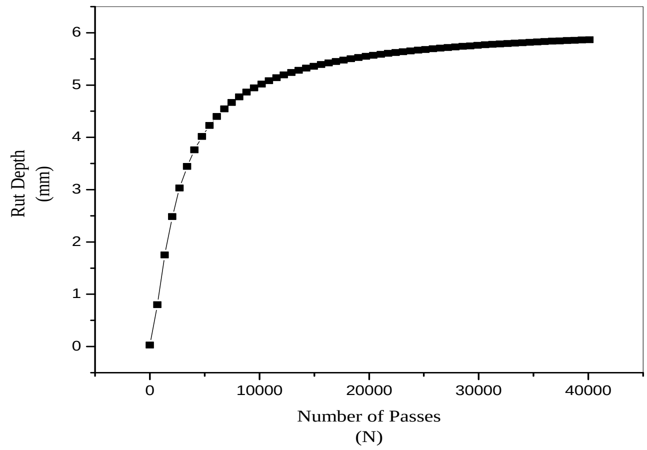


Fig. 3.5.2 Rut depth as a function of number of passes for BC using VG-30 binder at 40 °C

3.5.3 Effect of Temperature on rutting characteristics of BC mix using VG-30

Figure 3.5.3 shows effect of permanent deformation characteristics of BC mix prepared using VG-30 at 5 minutes compaction.

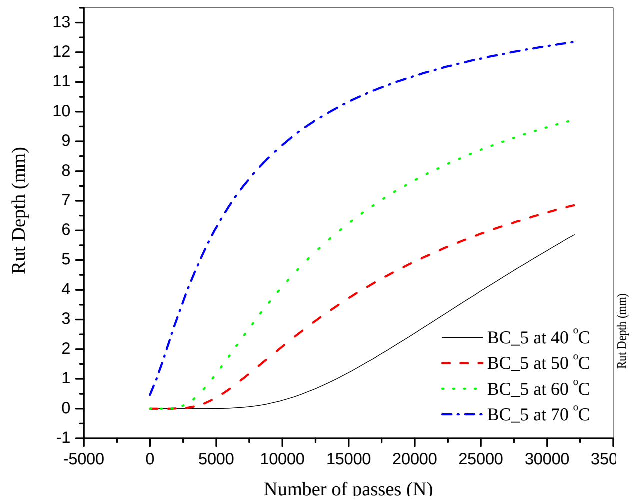


Fig 3.5.3 Rut depth plots showing effect of temperature for BC-VG-30

3.5.4 Effect of Temperature on rutting characteristics of DBM mix using VG-30:

Figure 3.5.4 shows effect of permanent deformation characteristics of DBM mix prepared using VG-30 at 5 & 15 minutes compaction.

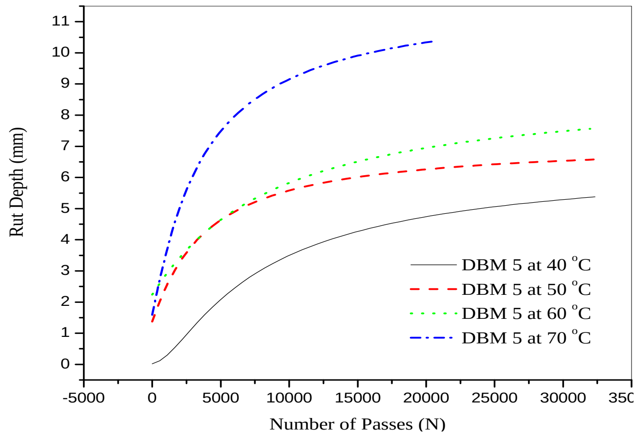


Fig 3.5.4 Rut depth plots showing effect of temperature for DBM-VG-30

3.5.5 Core Cutting

Core cutting is done to know the air voids of the sample. The results obtained from the core cutting samples are tabulated as below in Table 3.5.5

Table 3.5.5 Core cutting results

Sample	**Compaction Duration (min)**	**Air voids**
BC-VG-30	5	5.5475
BC-VG-30	10	4.0825
BC-VG-30	15	2.2775
DBM-VG-30	5	4.7925
DBM -VG-30	10	3.5075
DBM -VG-30	15	2.7775

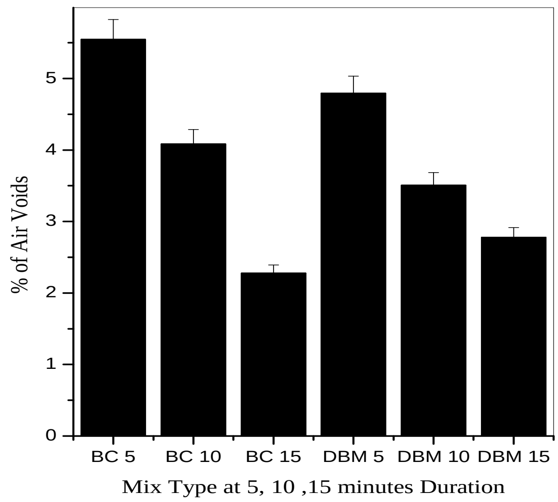


Fig 3.5.5 Comparison of air voids BC and DBM at different Compaction levels

3.5.6 Summary

In this chapter, the results obtained through laboratory investigations on asphalt mixes by varying mix type, test temperature, and air voids are discussed. Results obtained through laboratory investigations on asphalt binders and aggregates are also presented. Table 3.5.6 gives the brief details of the results of the dissertation work.

Table 3.5.6 Detailed results of the work

S.NO	**Mix**	**Grading**	**Binder Type**	**OBC (%)**	**Temperature**	**Rut Depth (mm)**	**Compaction Duration(min)**
1	BC	2	VG-30	6	40	5.48569	5
2	BC	2	VG-30	6	50	6.08976	5
3	BC	2	VG-30	6	60	7.6248	5
4	BC	2	VG-30	6	70	10.67828	5
5	BC	2	VG-30	6	40	2.89964	10
6	BC	2	VG-30	6	50	3.499982	10
7	BC	2	VG-30	6	60	7.09998	10
8	BC	2	VG-30	6	70	7.48962	10
9	BC	2	VG-30	6	40	0.89942	15
10	BC	2	VG-30	6	50	2.69982	15
11	BC	2	VG-30	6	60	4.49968	15
12	BC	2	VG-30	6	70	5.89764	15
13	DBM	2	VG-30	5.75	40	5.59962	5
14	DBM	2	VG-30	5.75	50	6.96452	5
15	DBM	2	VG-30	5.75	60	9.68822	5
16	DBM	2	VG-30	5.75	70	12.09632	5
17	DBM	2	VG-30	5.75	40	3.89041	10
18	DBM	2	VG-30	5.75	50	4.72956	10
19	DBM	2	VG-30	5.75	60	6.00912	10
20	DBM	2	VG-30	5.75	70	8.89996	10
21	DBM	2	VG-30	5.75	40	4.35642	15
22	DBM	2	VG-30	5.75	50	4.86249	15
23	DBM	2	VG-30	5.75	60	5.12628	15
24	DBM	2	VG-30	5.75	70	5.49982	15

4. DEVELOPMENT OF RUT DEPTH MODEL

4.1 General

In this chapter, we have discussed the simplest way to develop a three-stage permanent deformation model and presented.

4.2 Three Stage Equations

As discussed earlier in the literature review the three stage equations are shown in equations (4.1) to (4.4).

Primary Stage

$$\varepsilon_p = a N^b, N < N_{PS} \quad (4.1)$$

Secondary Stage

$$\varepsilon_p = \varepsilon_{PS} + c(N - N_{PS}), N_{PS} \le N < N_{ST} \quad (4.2)$$

Tertiary Stage

$$\varepsilon_p = \varepsilon_{ST} + d(e^{f(N - N_{ST})} - 1), N \ge N_{ST} \quad (4.3)$$

$$\varepsilon_{ST} = \varepsilon_{PS} + c(N_{ST} - N_{PS}) \quad (4.4)$$

Where,
ε_p= permanent strain,

N = number load repetitions,

a, b, c, d and e are = material constant,

N_{PS} = number of load repetitions related to the initiation of secondary stage,

ε_{PS} = permanent strain related to the initiation of secondary stage,

N_{ST} = number of load repetitions related to the initiation of tertiary stage and

ε_{ST} = permanent strain related to the initiation of tertiary stage.

Applying these equations to the data presented in the previous chapter resulted in the rut depth equations as shown in as Table 4.1. & Table 4.2

Table 4.1 Three stage equations for BC-VG-30

Sample	Primary Stage Equation	Secondary Stage Equation	Tertiary Stage Equation
40°C at 5 min	$\varepsilon_p = 0.004 * N^{0.699}$,R^2=0.914	None	None
50°C at 5 min	$\varepsilon_p = 0.568 * N^{0.241}$,R^2=0.940	None	None
60°C at 5 min	$\varepsilon_p = 0.412 * N^{0.284}$,R^2=0.989	None	None
70°C at 5 min	$\varepsilon_p = 0.413 * N^{0.332}$,R^2=0.957	None	None
40°C at 10 min	$\varepsilon_p = 0.001 * N^{0.766}$,R^2=0.996	None	None
50°C at 10 min	$\varepsilon_p = 0.067 * N^{0.379}$,R^2=0.911	None	None
60°C at 10 min	$\varepsilon_p = 0.015 * N^{0.591}$,R^2=0.992	None	None
70°C at 10 min	$\varepsilon_p = 0.178 * N^{0.385}$,R^2=0.993	None	None
40°C at 15 min	$\varepsilon_p = 0.029 * N^{0.334}$,R^2=0.885	None	None
50°C at 15 min	$\varepsilon_p = 0.506 * N^{0.168}$,R^2=0.881	None	None
60°C at 15 min	$\varepsilon_p = 0.114 * N^{0.354}$,R^2=0.846	None	None
70°C at 15 min	$\varepsilon_p = 0.448 * N^{0.251}$,R^2=0.832	None	None

Table 4.2 Three stage equations for DBM-VG-30

Sample	Primary Stage Equation	Secondary Stage Equation	Tertiary Stage Equation
40°C at 5 min	$\varepsilon_p = 0.006 * N^{0.724}$,R^2=0.934	None	None
50°C at 5 min	$\varepsilon_p = 0.325 * N^{0.172}$,R^2=0.993	None	None

60°C at 5 min	$\varepsilon_p = 0.018 * N^{0.372}$,R^2=0.922	None	None
70°C at 5 min	$\varepsilon_p = 0.082 * N^{0.495}$,R^2=0.937	None	None
40°C at 10 min	$\varepsilon_p = 0.003 * N^{0.633}$,R^2=0.996	None	None
50°C at 10 min	$\varepsilon_p = 0.04 * N^{0.445}$,R^2=0.996	None	None
60°C at 10 min	$\varepsilon_p = 0.358 * N^{0.271}$,R^2=0.778	None	None
70°C at 10 min	$\varepsilon_p = 0.07 * N^{0.453}$,R^2=0.992	None	None
40°C at 15 min	$\varepsilon_p = 0.087 * N^{0.382}$,R^2=0.821	None	None
50°C at 15 min	$\varepsilon_p = 0.113 * N^{0.372}$,R^2=0.799	None	None
60°C at 15 min	$\varepsilon_p = 0.142 * N^{0.356}$,R^2=0.778	None	None
70°C at 15 min	$\varepsilon_p = 0.190 * N^{0.330}$,R^2=0.778	None	None

4.3 Model Development

By the laboratory experimentation on asphalt mixtures, we can get the relationship between the number of load applications and permanent deformation in three distinct stages, namely the primary, secondary and tertiary stages. From the laboratory studies, the data collected is used as the database for the model development. Multiple regression analysis is used for model development. Rut depth being the dependent parameter, air voids and temperature are the independent parameters as shown in Equation 4.5. Table 4.3 shows properties of asphalt mixes and asphalt. Rut depth also depends on the type of binder. In this analysis only one binder (VG-30) is used.

$$\text{Rut Depth} = a_0+a_1*(\text{temperature})+a_2*(\text{air voids}) \qquad (4.5)$$

Where, a_0 = intercept, a_1 and a_2 = variables corresponding temperature and air voids respectively.

The results of multiple regression analysis are tabulated in the Table 4.4

Table 4.3 Parameters for carrying out multiple regression analysis

Sample No	Mix	Grading	Binder Type	OBC (%)	Temp	Rut Depth (mm)	Compaction (min)
1	BC	2	VG-30	6	40	5.48569	5
2	BC	2	VG-30	6	50	6.08976	5
3	BC	2	VG-30	6	60	7.6248	5
4	BC	2	VG-30	6	70	10.67828	5
5	BC	2	VG-30	6	40	2.89964	10
6	BC	2	VG-30	6	50	3.499982	10
7	BC	2	VG-30	6	60	7.09998	10
8	BC	2	VG-30	6	70	7.48962	10
9	BC	2	VG-30	6	40	0.89942	15
10	BC	2	VG-30	6	50	2.69982	15
11	BC	2	VG-30	6	60	4.49968	15
12	BC	2	VG-30	6	70	5.89764	15
13	DBM	2	VG-30	5.75	40	5.59962	5
14	DBM	2	VG-30	5.75	50	6.96452	5
15	DBM	2	VG-30	5.75	60	9.68822	5
16	DBM	2	VG-30	5.75	70	12.09632	5
17	DBM	2	VG-30	5.75	40	3.89041	10
18	DBM	2	VG-30	5.75	50	4.72956	10
19	DBM	2	VG-30	5.75	60	6.00912	10
20	DBM	2	VG-30	5.75	70	8.89996	10
21	DBM	2	VG-30	5.75	40	4.35642	15
22	DBM	2	VG-30	5.75	50	4.86249	15
23	DBM	2	VG-30	5.75	60	5.12628	15
24	DBM	2	VG-30	5.75	70	5.49982	15

Table 4.4 multiple regression analysis results

Mix	Independent Variable	Regression Parameters	Parameter Values	R^2
BC	Intercept	a_0	-43.7252	0.988512
	Temperature	a_1	0.196356	
	Air Voids	a_2	7.46221	
DBM	Intercept	a_0	-8.98442	0.975161
	Temperature	a_1	0.219971	
	Air Voids	a_2	1.221589	

Multiple regression analysis of BC and DBM resulted in Equations 4.6 and 4.7 respectively.

$$\text{Rut depth} = 0.196356(\text{Temperature}) + 7.46221(\text{Air Voids}) - 43.7252 \qquad (4.6)$$

$$\text{Rut depth} = 0.219971(\text{Temperature}) + 1.221589(\text{Air Voids}) - 8.98442 \qquad (4.7)$$

5. SUMMARY AND CONCLUSION

5.1 General

In this chapter summary and conclusions of the study are presented. The scope for the future research work is also discussed.

5.2 Summary

In this study an attempt has been made to develop rut depth model prediction with respect to temperature, air voids and binder type. Literature review on the fundamentals of rutting and the influence of binder type, temperature, zero shear, air voids are presented. Review of earlier studies revealed that binder type, air voids, temperature have significant influence on rutting. Rutting behaviour of BC and DBM mix prepared with VG-30 binder and compacted for 5, 10 and 15 minutes and tested at temperatures40, 50, 60, and 70 ^{0}C is reported in this in this work. Plots were drawn for permanent deformation against number wheel passes and comparisons are made considering the effect of temperature and air voids. Finally a model is formulated with rut depth as a function of temperature and air voids using multiple linear regression analysis.

6. CONCLUSION

Following are the conclusions drawn from the present study:

i. Temperature had a significant effect on rutting potential. Rutting resistance decreases with increase in temperature.
ii. Air voids also had a significant effect on rutting potential. Rutting increases with decrease in compaction duration.
iii. Good correlation was observed between rutting potential, temperature and air voids. Multiple regression analysis gave an R^2value of 0.98 for BC and 0.97 for DBM.

7. SCOPE FOR FUTURE RESEARCH WORK

The scope for further research work is summarized below:

i. The present study can be repeated with several binder types of unmodified, PMB, CRMB, and NRMB because harder binders are more viscous and more resistant to rutting. Aged binders can be used to determine the effect of aging.
ii. The present study can be repeated with different mix types such as BC, SDBC, SMA, DBM which are currently being used in India. All existing gradation types can be used to prepare the samples. The performance of asphalt mixes can be studied by adding fillers, and/or fibres (coconut or jute).
iii. Mixes can be prepared by using optimum binder content (OBC), less than OBC and more than OBC to compute the three stage permanent deformation response.

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