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PERFORMANCE EVALUATION OF MODIFIED BITUMINOUS MIX USING MIXED WASTE PLASTIC FOR ROADWAY PAVEMENTS

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ABSTRACT

Performance of bituminous mixes with addition of waste plastic is better as compared to conventional mixes in terms of strength and durability. Plastics, a versatile material and a friend to common man become a problem for the environment after its use. Their visibility has been perceived as a serious problem and made plastics a target in management of solid waste. Due to non-biodegradable properties plastics have long life. Uncontrolled burning of plastics leads to generation of many hazardous air pollutants depending upon the type of polymers. However, the end-of-life plastics can be recycled into a second life application but after every thermal treatment, degradation of plastics takes place to a certain extent. Waste plastic has been tried for construction of flexible pavement for performance and economy but very little work is available on its suitability for utilization in flexible pavements. Hence, the results available in literature cannot be applied directly here. So, there is a need to use plastic waste in economic and environmentally way for its safe disposal. Every new roads are build by using millions of tons of raw materials and natural stocks. This huge consumption leads to impoverishment of these resources on a daily basis. The engineering properties required for an ideal bituminous mix depends upon the properties of material used.

The objectives of the present study are to analyses the effect of varying proportion of waste plastic bottle (Polyethylene Terephthalate (PET)) on mechanical and volumetric properties of bituminous concrete and dense bituminous macadam mixes. To achieve the objective bituminous mixes investigations were carried out for mechanical properties like stability, flow, Marshall Quotient, retained stability, indirect tensile strength and volumetric properties like air voids, volume of bitumen, voids filled with bitumen, voids in mineral aggregates. These properties were investigated with varied percentages of waste plastic (0%, 3%, 5%, 7%, 10%, 12% and 15%)of bitumen content using dry process.

The results of the present study were compared with that of existing experimental work available in the literature and were found to be in coherence with existing data. The results of strength and durability tests suggest that waste plastic bottle (PET)) can safely be used even up to 15% of bitumen content but 7 % and 10% are the most efficient dose for bituminous concrete and dense bituminous macadam mixes for achieving stronger and durable flexible pavements.

1. INTRODUCTION

Recently, India's Road Ministry has increased the legal axle load for various categories of commercial vehicles by about 25%, leading to a notable rise in the presence of heavy vehicles on the roads. This surge in heavy vehicle traffic reduces the expected lifespan of pavements. To mitigate this issue, the use of high-quality materials or more effective construction techniques is recommended. The production of various waste materials has also escalated with population growth. The safe disposal of non-decaying waste materials with negligible salvage value poses an environmental challenge for both developed and developing nations. Plastics, although widely used and convenient, become environmental hazards once discarded. Visibility of these wastes has been perceived as serious problem and targeted in solid waste management.

Due to non-bio degradable properties plastics have long life. Uncontrolled burning of plastics leads to generation of many hazardous air pollutants which depend s upon the type of plastic .End of plastic life in one application can be recycled in to a second life application through thermal treatment; each thermal treatment leads to certain degree of degradation plastic quality. Several studies have concluded that incorporating waste plastic into bituminous mixes enhances their engineering properties. Waste plastic can be incorporated into bituminous mixes using two methods: the wet method, also known as polymer-modified bitumen, and the dry method. In the polymer-modified bitumen method, waste plastic is mixed directly with the bitumen. In the dry method, waste plastic is used to coat aggregates The Indian Road Congress (IRC: SP: 98-2013) provides "Guidelines for the Use of Waste Plastic in Hot Bituminous Mixes (Dry Process) in Wearing Courses," which outline the advantages and limitations of using plastic waste in flexible pavements.

2. SOURCES OFWASTEPLASTIC

Major areas of waste plastic collection are residential areas, streets, parks and waste dumps. Considerable amounts of plastic waste are found in municipal solid waste stream as shown in Figure1.2.Wasteplasticanditssources are giveninTable1.3.

Figure 1. Collection of Waste Plastic

THERMAL CHARACTERISTICS OF WASTE PLASTIC

Thermal behaviors of various polymers used as commercial plastic areas given in Table

Table.1 Details of thermal Behavior of Polymer

Sr. No.	Commercial Plastic	Plastics	Thickness (μ)	Softening Point(°C)
1	Cup	Polyethylene	160	100-120
2	Carry Bag	Polyethylene Terephthalate	215	170-180
3	Water Bottle	Polyethylene Terephthalate	215	170-180
4	Soft Drink Bottles	Polyethylene Terephthalate	215	170-180
5	Chocolate Covers	Polyester +Polyethylene+ Metalized Polyester	18	155
6	Covers of parcel	Polyethylene	55	100-120
7	Covers of supari	Polyester+ Polyethylene	65	120-135

IMPORTANCE OF RESEARCH TOPIC

The topic "Experimental Investigation on Bituminous Mixes using Plastic Waste" has been selected fort here search to determine suitability of waste plastic in road construction. This will help to increase the performance along with decrease in cost of road as well as saving of environment de gradationing terms of reduced pollution.

The mixing up of these wastes with other bio-degradable organic waste materials in the garbage of the urban areas generates problem. Therefore, attempts are being made in some are as to limit or even to prohibitt the use of plastic for packing and other common use, so as to control this "undesirable waste material" from getting mixed up with the other organic garbage. Being ,anon-biodegradable material, waste plastic does not decay over time.

So, there is a need to use plastic waste in environmental and eco-friendly way for its safe disposal. The prime significance of this study is to find out an alternate for disposal of plastic waste, that too with value addition in road construction along with economy.

3. OBJECTIVES OF THE STUDY

The objectives of the study "Experimental Investigation on Bituminous Mixes using Plastic Waste" aims to investigate the behavior of bituminous mixes with addition of waste plastic.

The main objectives of the study are:

(i) To determine optimum bitumen content and optimal dose of waste plastic (PET) in bituminous concrete (G-II) and dense bituminous macadam (G-II)bituminous mixes.

(ii) To study the effect of waste plastic on various mechanical, volumetric properties of bituminous mix and evolve utility of plastic waste in bituminous mixes.

(iii) To develop correlation between various properties of bituminous mixes and dependent variables.

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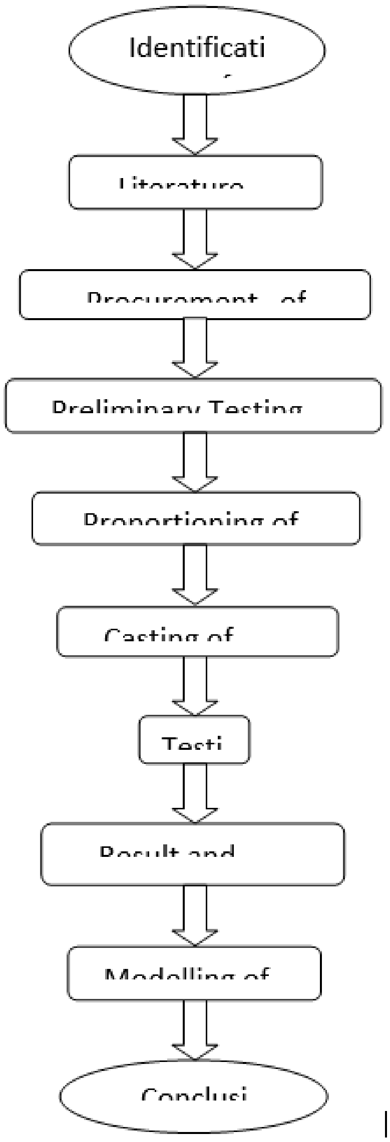
SCOPE OF PRESENT STUDY

The present study is carried out to investigate various mechanical and volumetric properties of bituminous mixes by incorporating of waste plastic. Bituminous mixes have been prepared using its constituent materials obtained from Yamuna Nagar quarry of Haryana region and IOCL Panipat Haryana. Waste plastic bottle (Polyethylene Terephthalate) was used as a modifier. The bituminous mixes are prepared as per the MoRT&H, 2013 specifications. Bituminous Concrete (Grade - II) and Dense Bituminous Macadam (Grade - II) mixes with varying proportions of PET from 0%, 3%, 5%, 7%, 10%, 12%, 15% of bitumen content are tested in present work.

The results of the study are accordingly valid for the type of materials used for preparing the bituminous mixes. However, the methodology and approach used may be applied with other types of waste plastic and raw material. Similar nature of results can be expected.

METHODOLOGY

The detailed methodology adopted in the present study is expressed in the form of a flow chart, Figure 3.1. The objectives of present study is to characterize the materials used for making bituminous mixes and mix designing of bituminous mixes with and without waste plastic using dry process, satisfying the requirements of strength and durability.



The methodology followed in the present research was decided with aim to–

- Study the information about the existing and possible future use of plastic waste in bituminous mixes.
- Study the effects of varied percentages of Polyethylene Terephthalate (PET) on mechanical and volumetric properties of Bituminous Concrete (Grade -II) and Dense Bituminous Macadam (Grade -II) mixes.
- Discuss the suitability of waste plastic (PET) in flexible pavement with special reference to India

MATERIALS USED

In order to achieve the defined objectives material comprising of aggregate (coarse and fine), filler, bitumen and waste plastic bottle (PET) was procured and tested for basic engineering properties as under:-

Bitumen

Bitumen is a petroleum product obtained through fraction distillation of crude. It is hydrocarbon material of pyrogenous origin, found in gaseous, liquid, semisolid form and is completely soluble in carbon disulphide and in carbon tetra chloride. Bitumen has mainly four grades depending upon viscosity such as VG-10, VG-20, VG-30 and VG-40. Bitumen sample of VG-30 grade. The sample was tested for various engineering properties required for bituminous mixes as per Indian Standard.

Aggregates

Aggregates constitute bulk of the total volume of bituminous mixes. Hence, it is very important to study the quality of aggregates. The durability and performance of road are influenced by characteristics of aggregates used in bituminous mixes. Aggregates are broadly classified in to two types, i.e. Coarse aggregate and fine aggregate. The properties of both the coarse and fine aggregates such as size, shape, specific gravity, hardness, surface texture, water absorption and gradation affect the quality of bituminous mixes.

Mineral Filler

"Filler may originate from fines in the aggregate or be added in the form of cement, lime or ground rock. Filler has an important effect on the voids content and the stiffness of the bitumen-fines matrix. It should have a plasticity index not greater than

4. This requirement does not apply, if filler is lime or cement" (MoRT&H, 2013, India).The grading requirement for the mineral filler as per Ministry of Road Transport and Highways specifications is given in Table 3.4. Hydrated lime of specific gravity 2.25 was used as mineral filler.

Modifier

The waste plastic bottle (Polyethylene Terephthalate (PET)) was used as a modifier. The plastic bottles were cut in uniform size, passing through 2.36mm sieve and retaining through 600µ sieve, so that the process of coating over aggregates could be carried out with ease. Properties of waste plastic (PET) are given in Table 3.5

BITUMINOUS MIX DESIGN

Bituminous mix designing is a process to determine optimum bitumen content along with appropriate proportioning of aggregate to fulfil the requirement of an ideal mix. The desirable properties of an ideal bituminous mix are stability, durability, flexibility, skid resistance and workability. Four mix design methods namely Marshall, Hveem, Hubbard-Field and Smith Triaxial are commonly used for mix designing of bituminous mix. The same have been described in the chapter on literature review. The requirements of bituminous mixes are explained as below -

- Sufficient stability to satisfy the service requirement so pavement without undue displacement.
- Sufficient amount of bitumen to ensure adurable pavement by coating and bonding of aggregate and water proofing of mix.
- Sufficient voids for slight amount of additional compaction due to traffic load
- Sufficient flexibility to prevent racking due to repeated application of loads.
- Sufficient workability during placing and compacting
- Sufficient resistance of pavement against skidding and a function of surface texture and bitumen content.

Designation of Bituminous Mix

Bituminous Concrete (Grade -II) and Dense Bituminous Macadam (Grade -II) mixes were used for study with varying percentage of PET and designated as BC_xP_y and $DBMxP_y$ given in Table 3.6.

Where, BC=Bituminous Concrete, DBM= Dense Bituminous Macadam, x =Percentage of Bitumen Content, P=Polyethylene Terephthalate(PET) y = Percentage of PET Content

Designation of Bituminous Mixes

Bituminous Concrete Mixes				
$BC_{5.0}$-P_0	$BC_{5.2}$-P_0	$BC_{5.4}$-P_0	$BC_{5.6}$-P_0	$BC_{5.8}$-P_0
$BC_{5.0}$-P_4	$BC_{5.2}$-P_4	$BC_{5.4}$-P_4	$BC_{5.6}$-P_4	$BC_{5.8}$-P_4
$BC_{5.0}$-P_6	$BC_{5.2}$-P_6	$BC_{5.4}$-P_6	$BC_{5.6}$-P_6	$BC_{5.8}$-P_6

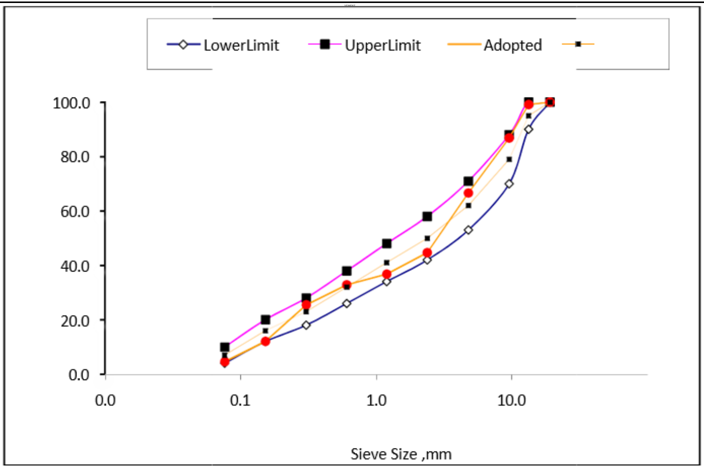
$BC_{5.0}$-P_8	$BC_{5.2}$-P_8	$BC_{5.4}$-P_8	$BC_{5.6}$-P_8	$BC_{5.8}$-P_8
BC5.0-P10	BC5.2-P10	BC5.4-P10	BC5.6-P10	BC5.8-P10
BC5.0-P12	BC5.2-P12	BC5.4-P12	BC5.6-P12	BC5.8-P12
BC5.0-P14	BC5.2-P14	BC5.4-P14	BC5.6-P14	BC5.8-P14
Dense Bituminous Macadam Mixes				
$DBM_{4.1}$-P_0	$DBM_{4.3}$-P_0	$DBM_{4.5}$-P_0	$DBM_{4.7}$-P_0	$DBM_{4.9}$-P_0
$DBM_{4.1}$-P_4	$DBM_{4.3}$-P_4	$DBM_{4.5}$-P_4	$DBM_{4.7}$-P_4	$DBM_{4.9}$-P_4
$DBM_{4.1}$-P_6	$DBM_{4.3}$-P_6	$DBM_{4.5}$-P_6	$DBM_{4.7}$-P_6	$DBM_{4.9}$-P_6
$DBM_{4.1}$-P_8	$DBM_{4.3}$-P_8	$DBM_{4.5}$-P_8	$DBM_{4.7}$-P_8	$DBM_{4.9}$-P_8
DBM4.1-P10	DBM4.3-P10	DBM4.5-P10	DBM4.7-P10	DBM4.9-P10
DBM4.1-P12	DBM4.3-P12	DBM4.5-P12	DBM4.7-P12	DBM4.9-P12
DBM4.1-P14	DBM4.3-P14	DBM4.5-P14	DBM4.7-P14	DBM4.9-P14

Proportioning of Material

Proportioning of material affects the mechanical and volumetric properties of bituminous mixes. So, it is essential to decide the best proportion of constituting materials for bituminous mixes. In the present study analytical method of proportioning was used for proportioning of aggregates.

Proportioning of Aggregate for Bituminous Concrete (Grade-II) Mix

Sieve Size (mm)	Cumulative % by Weight of Total Aggregate Passing				Gradation		
	Designation				MoRT & H, 2013 Specifications for Grading		Observed Grading (A:B:C: D) (34:14:50:02)
	Aggregates		Stone Dust C	Lime D	Range	Mean	
	13.2mm A	6.0mm B					
19.0	100.0	100.0	100.0	100.0	100	100	100
13.2	97.4	100.0	100.0	100.0	90 -100	95	100
9.5	61.2	100.0	100.0	100.0	70 - 88	79	87
4.75	11.9	92.3	95.4	100.0	53 - 71	62	67
2.36	1.4	8.1	82.1	100.0	42 - 58	50	45
1.18	0.0	2.4	68.9	100.0	34 - 48	41	37
0.600	0.0	2.0	61.1	100.0	26 - 38	32	33
0.300	0.0	1.8	46.4	100.0	18 - 28	23	25
0.150	0.0	1.4	19.9	96.0	12 - 20	16	12
0.075	0.0	0.6	7.8	88.0	4 - 10	7	5



Gradation of Bituminous Concrete (Grade–II)Mix

Proportioning of Material for Dense Bituminous Macadam Mix

“Dense bituminous macadam is used as a base and profile corrective course in using multiple layers on a previously prepared base or sub-base. The thickness of a single layer shall be 50mm to 100mm” (MoRT&H, 2013, India).

Composition of Dense Graded Bituminous Macadam

Grading	1	2
Nominal Aggregate Size	37.5 mm	26.5 mm
Layer Thickness	75-100mm	50-75mm
IS Sieve(mm)	Cumulative % by Weight of Total Aggregates Passing	
45	100	-
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	28-42	28-42
1.18	-	-
0.6	-	-
0.3	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen Content % by Mass of Total Mix	Min4.0	Min4.5

Proportioning of Material for Dense Graded Bituminous Macadam (Grade -II) Mix

Sieve Size (mm)	Cumulative % by Weigh to Total Aggregate Passing					Gradation		
	Designation					MoRT&H, 2013 Specifications for Grading		Observed Grading (A:B:C:D: E) (30:23:10:35:02)
	Aggregates			Stone Dust D	Lime E			
	19mm A	13.2mm B	6.0mm C			Range	Mean	
37.5	100.0	100.0	100.0	100.0	100.0	100	100	100.0
26.5	100.0	100.0	100.0	100.0	100.0	90 - 100	95	100

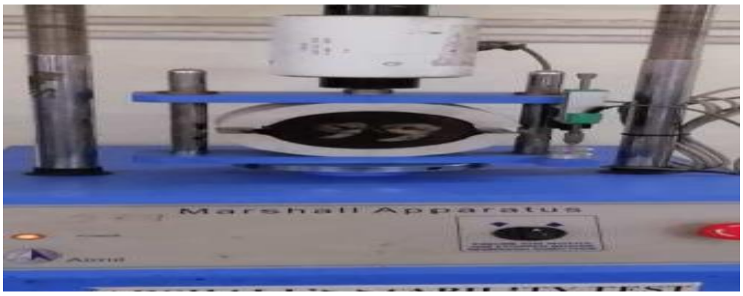
19.0	80.4	100.0	100.0	100.0	100.0	71 - 95	83	94
13.2	8.6	97.4	100.0	100.0	100.0	56 - 80	68	72
4.75	0.0	11.9	92.3	95.4	100.0	38 - 54	46	47
2.36	0.0	1.4	8.1	82.1	100.0	28 - 42	35	32
0.300	0.0	0.0	1.8	46.4	100.0	7 - 21	14	18
0.075	0.0	0.0	0.6	7.8	88.0	2 - 8	5	3

TESTING OF SPECIMENS

Marshall Stability Test

Marshall Test is the universally test carried out to determine the optimum bitumen content required for bituminous mixes. Stability value is defined as maximum load carried out by a compacted bituminous mix specimen at 60°C. Prepared Marshall Mould were weight in air and water before keeping them in water bath at 60°C for 30 minutes. The specimen were placed under Marshall loading frame as shown in Figure 3.6, immediately after taking out from water bath and strained control loading was given at a rate of 50mm per minute. Stability value (load) was recorded in data acquisition system forun-conditioned(30 Minuteat60°C)and conditioned specimens (24 hour at 60°C). Corrected Marshall Stability value was obtained by multiplying the observed stability value with correlation factor as given in Table .

Marshall Loading Frame for Stability Test



Correlation Factors for Marshall Stability Values

Volume of Specimen,cm^3	Approximate Thickness Of Specimen, mm	Correlation Factor
200-213	25.4	5.56
214-225	27.0	5.00
226-237	29.6	4.55
238-250	30.2	4.17
251-264	31.8	3.85
265-276	33.3	3.57
277-289	34.9	3.33
290-301	36.5	3.03
302-316	38.1	2.78
317-328	39.7	2.50
329-340	41.3	2.27
341-353	42.9	2.08
354-367	44.5	1.92
368-379	46.0	1.76
380-392	47.6	1.67
393-405	49.2	1.56
406-420	50.8	1.47

421-431	52.4	1.39
432-443	54.0	1.32
444-456	55.6	1.25
457-470	57.2	1.19
471-482	58.8	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	63.5	1.00
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.9	0.86
574-585	71.5	0.83
586-598	73.0	0.81
599-610	74.6	0.78
611-625	76.2	0.76

Requirements for Conventional Bituminous Mixes

Sr. No.	Properties	MoRT&H,2013Specifications
1	Marshall Stability Value, kN	Min. 9.0
2	Flow Value, mm	2-4
3	Theoretical Max. Density, gm/cc	-
4	Bulk Density(G_m),gm/cc	-
5	Volume of Air Voids (Vv), %	3-5
6	Volume of Bitumen (V_b)%	-
7	Voids in Mineral Aggregate (VMA),%	>15
8	Voids Filled with Bitumen (VFB)%	65-75

Requirements for Waste Plastic Modified Dense Graded Bituminous Mixes

Sr.No.	Properties	IRCSP-98, 2013Specification
1	Marshall Stability minimum (kNat60 °C)	12.0
2	Marshall Flow (mmat60°C)	2-4
3	Marshall Quotient (kN/mm)	2.5-5
4	Air Voids (%)	3-5
5	Retained Stability(%)	98
6	Indirect Tensile Strength, minimum(N/mm^2)	0.9
7	Voids in Mineral Aggregates(%)	>16
8	Voids Filled with Bitumen(%)	65-75

Retained Stability Test

"Stripping is due to the fact that some aggregates have greater affinity towards water than with binder and this displacement depends on the physic-chemical force acting on the system. In bituminous mixes with high volume of voids; there is risk of stripping, resulting in a loss of internal cohesion and possibly disintegration of the surfacing" Retained stability is determined for bituminous mixes to evaluate the potential damage that water may cause to bituminous pavement. It is the ratio of Marshall Stability of conditioned specimen (24 hour at 60°C) to un-conditioned specimen (30 Minute at 60°C). Marshall Stability Test was performed for retained stability value on conventional and modified mixes.

$$\text{Retained Stability(\%)} = \frac{\text{Marshall Stability of Conditioned Specimen (24 hour at 60°C)}}{\text{Marshall Stability un-conditioned Specimen (30 Minute at 60°C)}} \times 100$$

Indirect Tensile Strength Test

Tensile characteristics of bituminous mixes are determined by indirect tensile strength (ITS) test. The specimens for indirect tensile strength test were casted in same manner as of Marshall Specimens. The indirect tensile strength(ITS) of conditioned(60°C for 24 hour) and unconditioned specimen (25°C, dry) (both conventional and modified mixes) was determined using Marshall Test apparatus as per AASHTO T283. "The ITS test was performed by loading a Marshall Specimen with single compressive load, which act parallel to and along vertical diametrical plane asshowninFigure3.7. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load along the vertical diametrical plane, which ultimately causes the specimen to fail by splitting along the vertical diameter" (AASHTO T283). The load at failure was recorded and the indirect tensile strength was calculated using following equation -

$$\text{Indirect Tensile Strength (ITS)} = \frac{2P_{max}}{\pi t d}$$

Where,

P max=Maximum Load(N),

t=Thickness of Specimen(cm), d = Diameter of Specimen (cm)

Marshall Loading Frame for Indirect Tensile Strength Test

The ratio of tensile strength of conditioned specimen to un-conditioned specimen is known as tensile strength ratio (TSR). The tensile strength ratio (TSR) was calculated using equation given below-

$$\text{Tensile Strength Ratio(TSR)} = \frac{\text{Indirect Tensile Strength (conditioned)}}{\text{Indirect Tensile Strength (un-conditioned)}}$$

4. RESULT

VOLUMETRIC PROPERTIES OF BITUMINOUS CONCRETE MIXES

Bulk Density of Bituminous Concrete Mixes

The results for bulk density (G_m) of bituminous concrete mixes at different PET content are given in Table 4.1. It is clear from the Table 4.1 and Figure 4.1 that bulk density increases with increase in PET content up to 8%, after that there is decrease in bulk density. This decrease in bulk density is due to increase in voids after 8% PET content. The maximum bulk density for conventional and modified mixes is 2.305gm/cc and 2.324gm/cc corresponding to $BC_{5.8}$-$P_0$and $BC_{5.8}$-P_8mixes.

Bulk Density of Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Bulk Density(gm/cc)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	2.264	2.266	2.275	2.275	2.259	2.251	2.240
2	5.2	2.271	2.273	2.278	2.279	2.272	2.268	2.262

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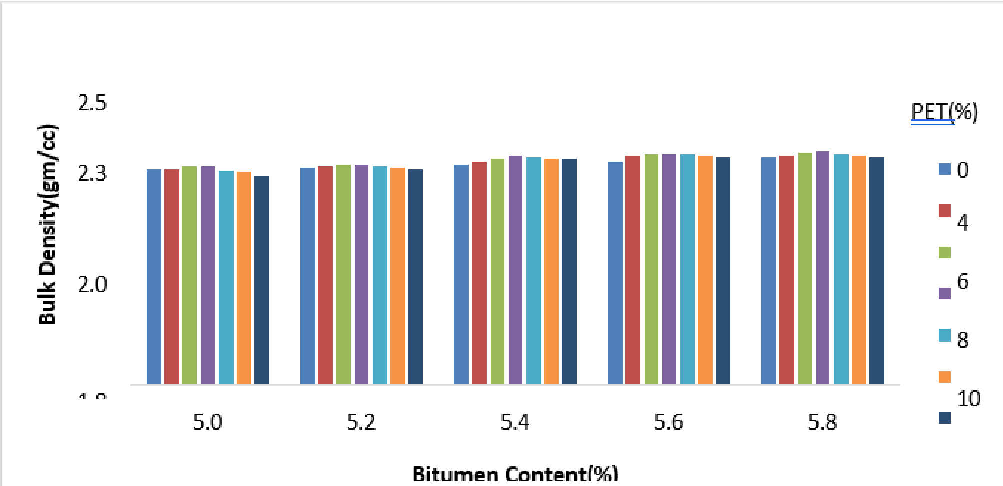
3	5.4	2.279	2.287	2.299	2.309	2.306	2.302	2.298
4	5.6	2.290	2.308	2.314	2.316	2.313	2.309	2.303
5	5.8	2.305	2.309	2.321	2.324	2.316	2.312	2.307



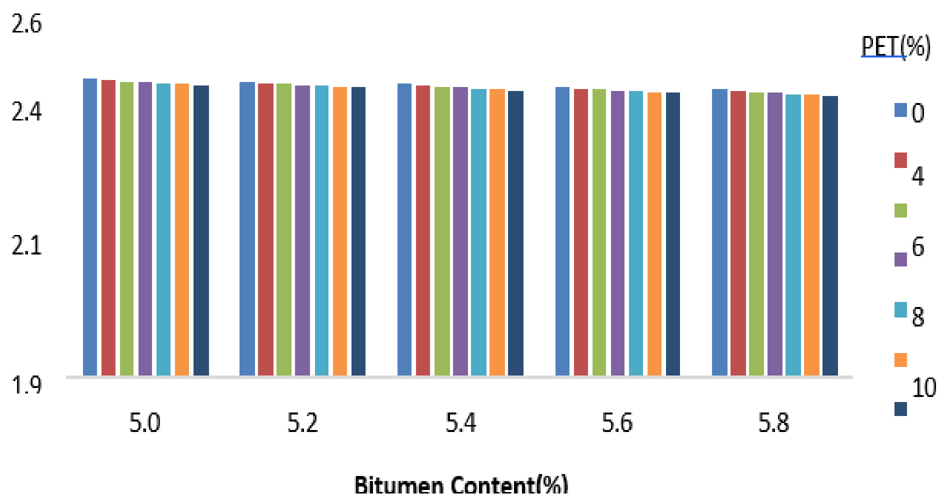
Bulk Density of Bituminous Concrete Mixes at different PET Content

Theoretical Density of Bituminous Concrete Mixes

Table 4.2 and Figure 4.2 show the theoretical density (G_t) of bituminous concrete mixes. Theoretical density of modified bituminous concrete mixes decreases with increase in PET content. This decrease in theoretical density may be due to the lower specific gravity of PET. Maximum value of theoretical density is 2.439gm/cc for conventional mix ($BC_{5.0}$-P_0) and 2.434gm/cc for modified mix ($BC_{5.0}$-P_4). The minimum value of theoretical density is found to be 2.392gm/cc for $BC_{5.8}$-P_{14}mix.

Table Theoretical Density of Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Theoretical Density(gm/cc)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	2.439	2.434	2.432	2.430	2.427	2.425	2.423
2	5.2	2.430	2.427	2.424	2.422	2.420	2.417	2.415
3	5.4	2.424	2.419	2.417	2.415	2.412	2.410	2.407
4	5.6	2.417	2.412	2.410	2.407	2.405	2.402	2.400
5	5.8	2.410	2.405	2.402	2.400	2.397	2.395	2.392



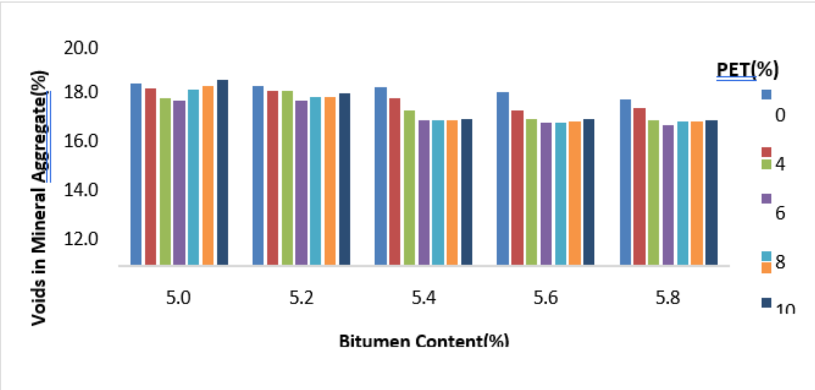
Volume of Air Voids in Bituminous Concrete Mixes

Total volume of air pockets between the coated aggregate particles throughout a compacted paving mixture is known as volume of air voids (V_v). The amount of air voids in a mixture is extremely important and closely related to stability, durability andpermeability.ItisevidentfromtheTable4.3andFigure4.3thatvolumeofair

voids for bituminous concrete mixes decreases as the PET content increases up to 8% and increases with further increase in PET content. The decreases in volume of air voids indicate better cohesion between bitumen and PET coated aggregate. The volume of air voids decreases as the bitumen content increase. $BC_{5.0}$-$P_{14}$and $BC_{5.8}$-P_8 mixes reported maximum and minimum value of volume of air voids respectively.

Voids in Mineral Aggregate for Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Voids in Mineral Aggregate(%)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	18.37	18.14	17.68	17.58	18.06	18.25	18.54
2	5.2	18.25	18.04	18.03	17.58	17.73	17.76	17.91
3	5.4	18.17	17.70	17.15	16.65	16.67	16.70	16.74
4	5.6	17.96	17.12	16.74	16.55	16.56	16.61	16.71
5	5.8	17.61	17.25	16.67	16.43	16.61	16.62	16.68



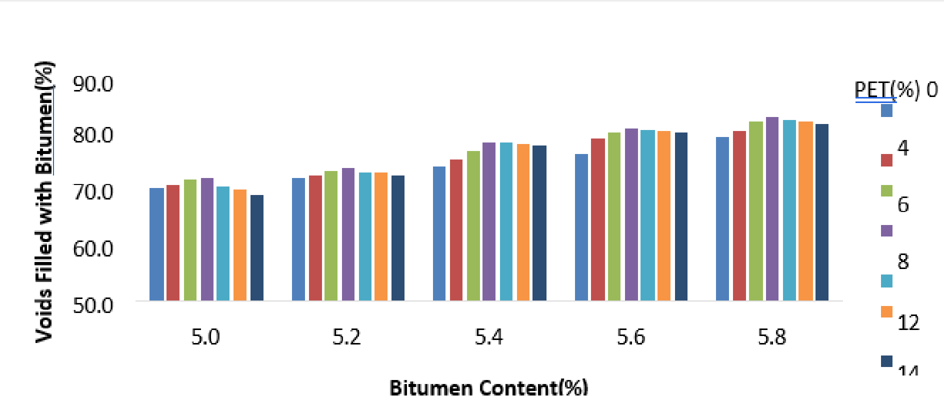
Voids in Mineral Aggregate for Bituminous Concrete Mixes at different PET Content

Voids Filled with Bitumen for Bituminous Concrete Mixes

Voids filled with bitumen (VFB) are the voids in the mineral aggregate frame work filled with bitumen binder. VFB increases as the bitumen content increase for conventional mixes. The value of voids filled with bitumen increases up to 8% PET content for all the modified mixes and decrease with further increase in PET content. This decrease in voids filled with bitumen indicates that effective bitumen film thickness between aggregates decreases, which will result in cracking and lower durabilityof bitumen mixture, since bitumen perform the filling and healing effects to improve the flexibility of mixture. The maximum and minimum values of VFB are 80.86% and 59.39% corresponding to $BC_{5.8}$-$P_8$and $BC_{5.0}$-P_{14}mixes respectively.

Voids Filled with Bitumen for Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Voids Filled with Bitumen(%)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	61.04	61.89	63.54	63.80	61.63	60.69	59.39
2	5.2	64.06	64.86	65.92	66.51	65.66	65.35	64.55
3	5.4	67.10	69.15	71.47	73.88	73.58	73.21	72.85
4	5.6	70.71	74.80	76.41	77.49	77.12	76.89	76.37
5	5.8	75.16	76.93	79.74	80.86	79.94	79.37	78.80

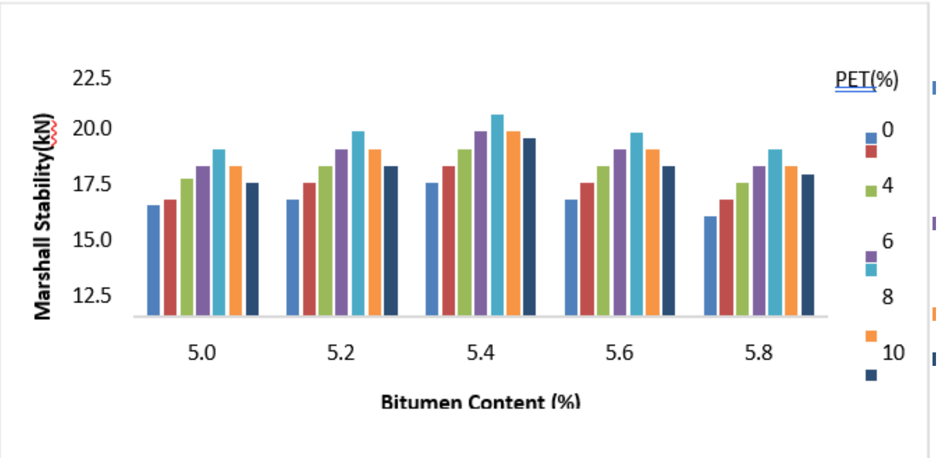


Voids Filled with Bitumen for Bituminous Concrete Mixes at different PET Content

MECHANICAL PROPERTIES OF BITUMINOUS CONCRETE MIXES

Un-conditioned Marshall Stability of Bituminous Concrete Mixes

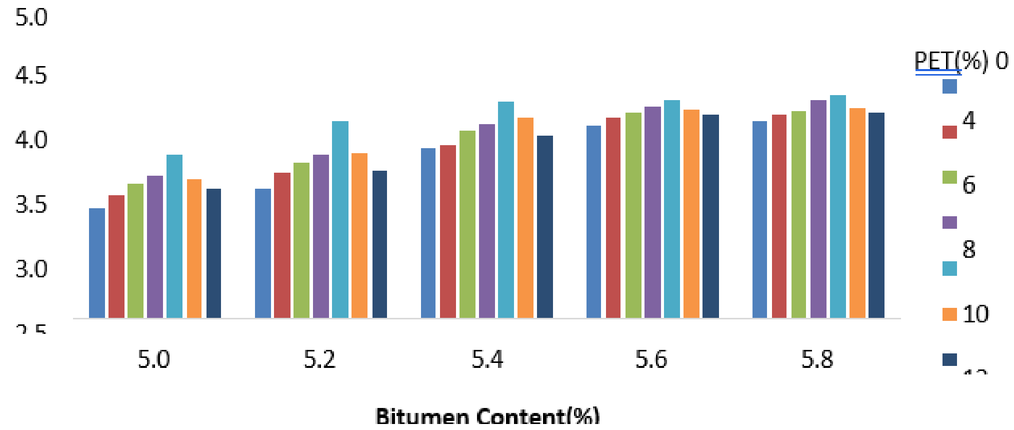
Sr. No.	Bitumen (%)	Un-conditioned Marshall Stability 4.(kN)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	15.82	16.11	17.21	17.86	18.76	17.87	16.98
2	5.2	16.11	16.98	17.87	18.78	19.68	18.77	17.88
3	5.4	16.99	17.88	18.78	19.67	20.55	19.67	19.32
4	5.6	16.11	16.98	17.87	18.77	19.64	18.76	17.87
5	5.8	15.22	16.11	16.99	17.88	18.78	17.89	17.46



Un-conditioned Marshall Stability of Bituminous Concrete Mixes at different PET Content

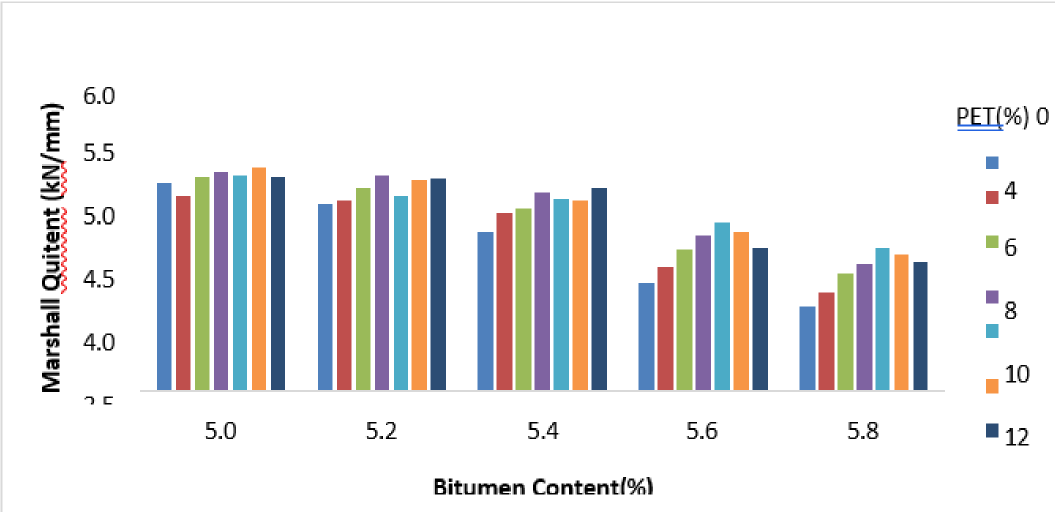
Flow Value of Bituminous Concrete Mixes

Sr. No.	Bitumen (%)	Flow(mm)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	3.10	3.23	3.34	3.42	3.62	3.39	3.29
2	5.2	3.29	3.45	3.54	3.62	3.96	3.65	3.47
3	5.4	3.70	3.73	3.87	3.93	4.16	3.99	3.82
4	5.6	3.92	4.00	4.04	4.10	4.17	4.08	4.02
5	5.8	3.96	4.03	4.06	4.17	4.22	4.09	4.05



Marshall Quotient of Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Marshall Quotient(kN/mm)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	5.10	4.98	5.16	5.22	5.18	5.27	5.16
2	5.2	4.90	4.92	5.05	5.19	4.97	5.14	5.15
3	5.4	4.60	4.80	4.85	5.00	4.94	4.93	5.06
4	5.6	4.10	4.25	4.43	4.58	4.71	4.60	4.45
5	5.8	3.85	4.00	4.19	4.29	4.45	4.38	4.31



Marshall Quotient of Bituminous Concrete Mixes at different PET Content

Conditioned Marshall Stability of Bituminous Concrete Mixes

Marshall Stability Values of conditioned specimens for bituminous concrete mixes are shown in Table 4.10 and Figure 4.10. Conditioned stability of Marshall Specimen is less as compared to un-conditioned stability, which shows the effect of water on the bituminous mixes. The conditioned stability value of bituminous concrete mixes with different binder content increase with increase in PET content up to 10%. Further increase in PET content reduces the conditioned stability value.

This increase in stability value by adding PET attributed to better adhesion developed between the materials of modified mix and show reduction in adhesiveness beyond 10% PET content. The maximum value of stability is 20.17 kN for modified mix of designation $BC_{5.4}$-P_{10}, which is 34.28% higher as compared to conventional mix with same bitumen content. The maximum value of stability, after conditioned, for conventional mix is 14.92 kN, which is 12.18% lower than un-conditioned sample.

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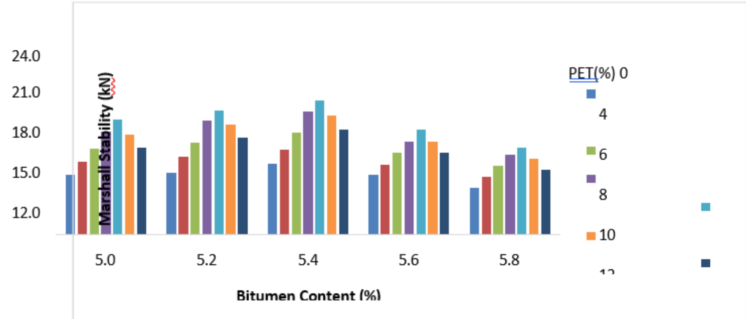
Table : 2 Conditioned Marshall Stability of Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Conditioned Marshall Stability (kN/mm)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	13.99	15.10	16.21	17.65	18.57	17.37	16.22
2	5.2	14.19	15.53	16.70	18.52	19.33	18.18	17.08
3	5.4	14.92	16.07	17.51	19.30	20.17	18.93	17.73
4	5.6	13.96	14.87	15.82	16.78	17.75	16.78	15.81
5	5.8	12.92	13.82	14.72	15.65	16.27	15.35	14.43



Conditioned Marshall Stability of Bituminous Concrete Mixes at different PET Content

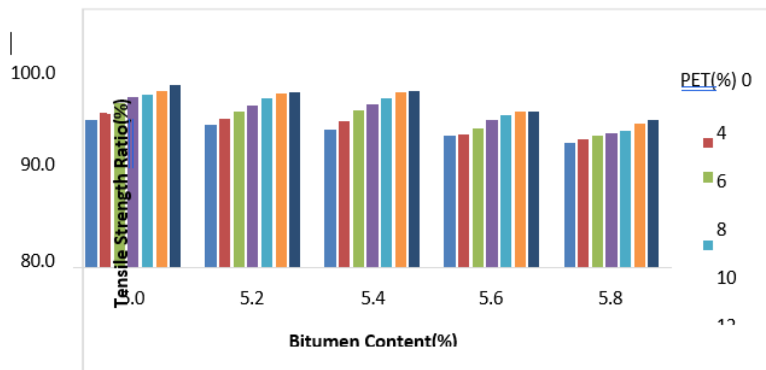
Retained Stability of Bituminous Concrete Mixes

It is evident from there sults given in Table 4.11 and Figure 4.11that retained stability increases with increase in PET content up to 8 to 10% for bituminous concrete mixes. The decrease in retained stability value after 8 to 10% PET content attributes to the reduced adhesion between the PET coated aggregate and bitumen. Maximum value of retained stability is 98.99% for $BC_{5.0}$-P_{10} mix. Mixes $BC_{5.0}$-P_{8}, $BC_{5.0}$-P_{10}, $BC_{5.2}$-P_{8}, $BC_{5.2}$-P_{10}, $BC_{5.4}$-P_{8} and $BC_{5.4}$-P_{10} fulfil the requirement of retained stability value as per IRC SP-98, 2013.

Tensile Strength Ratio of Bituminous Concrete Mixes

Tensile Strength Ratio of Bituminous Concrete Mixes at different PET Content

Sr. No.	Bitumen (%)	Tensile Strength Ratio(%)						
		PET(%)						
		0	4	6	8	10	12	14
1	5.0	90.14	91.59	93.76	94.89	95.41	96.28	97.46
2	5.2	89.28	90.48	91.89	93.16	94.58	95.73	95.92
3	5.4	88.26	90.12	92.32	93.45	94.65	95.96	96.23
4	5.6	86.94	87.25	88.56	90.17	91.35	91.89	92.03
5	5.8	85.46	86.24	86.95	87.58	88.09	89.43	90.28



Bulk Density of Dense Bituminous Macadam Mixes at different PET Content

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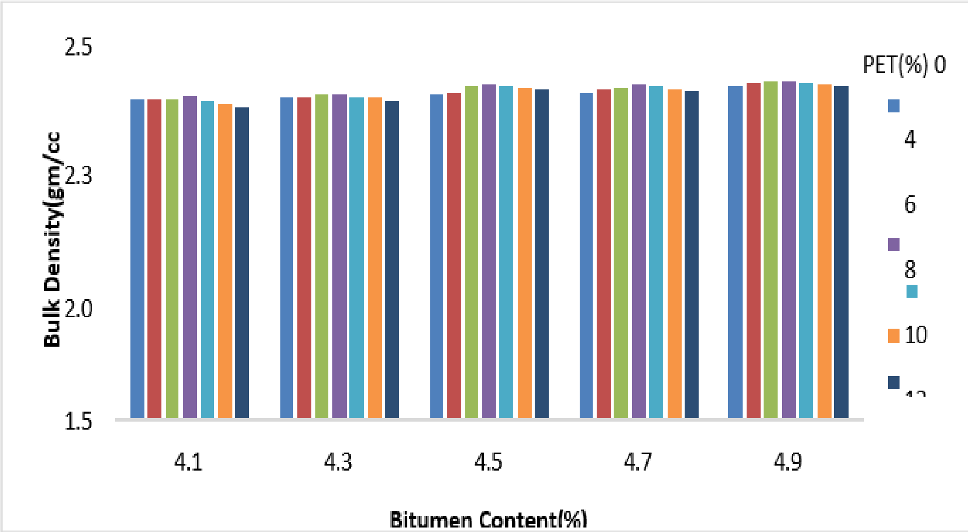
VOLUMETRIC PROPERTIES OF DENSE BITUMINOUS MACADAM MIXES

Sr. No.	Bitumen (%)	Bulk Density (gm/cc)						
		PET(%)						
		0	4	6	8	10	12	14
1	4.1	2.355	2.356	2.358	2.368	2.353	2.345	2.334
2	4.3	2.361	2.362	2.371	2.373	2.364	2.360	2.354
3	4.5	2.371	2.375	2.391	2.398	2.391	2.386	2.382
4	4.7	2.376	2.384	2.386	2.398	2.392	2.385	2.379
5	4.9	2.392	2.400	2.403	2.407	2.402	2.397	2.392



Bulk Density of Dense Bituminous Macadam Mixes at different PET Content

OPTIMUM BITUMEN CONTENT

The amount of bitumen that fulfils the requirements of an ideal bituminous mix is known as optimum bitumen content. The durability of the bituminous pavement can be enhanced by the impermeability achieved. A minimum amount of bitumen is essential to prevent the aggregates from being pulled out by the abrasive actions of moving vehicles on the carriageway. At the same time it should not be too high because it would reduce stability.

The optimum bitumen content for conventional bituminous concrete and dense bituminous macadam achieves the best performance (fulfil the minimum requirements) at 5.66% and 4.82% respectively. PET modified mixes $BC_{5.4}$-P_8 and $DBM_{4.5}$-P_{10}also achieves the best performance and fulfils the minimum requirement as per IRC SP-98, 2013 specifications. Use of PET waste plastic reduces the optimum bitumen content by 4.59% for bituminous concrete mixes and 6.64% for dense bituminous macadam.

5. CONCLUSIONS

The present study aims at utilizing polyethylene terephthalate (PET), a non- biodegradable plastic waste, in bituminous mixes (bituminous concrete (G-II) and dense bituminous macadam (G-II)), with the intension to improve quality of bituminous mix along with a sustainable solution to voluminous plastic waste disposal.

In order to achieve the desired objectives, a series of experimental investigation was carried out on two most commonly used bituminous mixes i.e. dense bituminous macadam and bituminous concrete. Using Marshall Method of mix design, job mix formula was evolved for both the mixes and optimum bitumen content was determined.

A non-biodegradable, plastic waste namely "polyethylene terephthalate (PET)", commonly used in plastic bottle, generated in huge volume, was used in different percentages form 4 to 14% (at an increment of 2%) in both the selected bituminous mixes (DBM and BC) and modified mixes were evaluated. The waste plastic was added through dry process of mixing.

Volumetric and mechanical properties of conventional and modified mixes were observed/evaluated/calculated.

On the basis of experimental and analytical observation on conventional and modified mixes following conclusions are drawn.

(i) Stability value of bituminous mixes increases with addition of PET – waste plastic. An increase of more than 24%and 10%was observed in case of BC and DBM respectively, at optimal dose of PET content, as compared to conventional mixes.

(ii) Higher value of Marshall Quotient in case of PET modified bituminous mixes reveal stiffer bituminous mixes, more suitable for heavily trafficked roads.

(iii) Tensile strength ratio (TSR) for conventional bituminous concrete and dense bituminous macadam (at optimum bitumen content) was 86.50% and 85.19% respectively. PET modified mixes have higher TSR i.e. 93.45% and 93.70% for BC and DBM respectively. This indicates that PET modified mixes are less susceptible to moisture damage as compared to conventional mix.

(iv) Optimum bitumen content for conventional bituminous concrete and dense bituminous macadam mix was observed as 5.66% and 4.82% respectively. A reduction in optimum bitumen content was observed with use of waste plastic (PET), which is 4.59% in case of bituminous concrete and 6.64% in case of dense bituminous macadam mix.

(v) Optimal dose of waste plastic (polyethylene terephthalate (PET)) was observed as 8% and 10% for bituminous concrete and dense bituminous macadam mix.

(vi) Utilization of waste plastic (PET) in bituminous mixes, using dry process, is a cost effective solution for safe disposal of waste plastic with improved engineering properties of bituminous mixes.

6. SCOPE FOR FUTURE WORK

Some of the suggestions for further studies concerning modified bituminous mixes used in flexible pavements are given below:

- With other types of waste plastic.
- Study bituminous mixes with different combination of waste plastic.
- Study with emulsion and cut back in respect of bitumen.
- Study recycled aggregate in bituminous mixes with addition of waste plastic.
- Study the field performance of flexible pavement using waste plastic modified material.

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