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STUDY ON USE OF WASTE PLASTIC IN BITUMINOUS CONCRETE MIXES

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ABSTRACT-*Today, every vital sector of the economy starting from agriculture to packaging, automobile, building construction, communication or InfoTech has been virtually revolutionized by the applications of plastics. In recent years, applications of plastic wastes have been considered in road construction with great interest in many developing countries. The use of these materials in road making is based on technical, economic, and ecological criteria. The lack of traditional road materials and the protection of the environment make it imperative to investigate the possible use of these materials carefully India has a large network of metro cities located in different parts of the country and many more are planned for the near future. Several million metric tons plastic wastes are produced every year in India. Traditionally soil, stone aggregates, sand, bitumen cement etc. are used for road construction. Natural materials being exhaustible in nature, its quantity is declining gradually. Also, cost of extracting good quality of natural material is increasing. Concerned about this, the scientists are looking for alternative materials for highway construction, and plastic wastes product is one such category.*

Keywords: *Bituminous concrete , Waste plastic, Marshall stability, Highway, Road construction*

I. INTRODUCTION

Waste plastic materials can be suitably utilized in highway construction, as a result of this the pollution and disposal problems may be partly reduced. In the absence of other outlets, these solid wastes have occupied several acres of land around plants throughout the country. Keeping in mind the need for bulk use of these solid wastes in India, it was thought expedient to test these materials and to develop specifications to enhance the use of these plastic wastes in road making, in which higher economic returns may be possible. The possible use of these materials should be developed for construction of low-volume roads in different parts of our country. The necessary specifications should be formulated and attempts are to be made to maximize the use of solid wastes in different layers of the road pavement. On heating at 100 - 160°C, plastics such as polyethylene, polypropylene and polystyrene, soften and exhibit good binding properties. Blending of the softened plastic with bitumen results in a mixed that is amenable for road laying. The mixed has been used to lay roads of length up to 1,500 km in the state of Maharashtra. Other states like Tamil Nadu, Karnataka, Pondicherry, Kerala and Andhra Pradesh have also laid test roads. These roads have withstood loads due to heavy traffic, rain and temperature variation. Under this circumstance, an alternate use for the waste plastics is also the needed. Thinner polythene carry bags are most abundantly disposed of wastes, which do not attract the attending rag pickers for collection for onward recycling, for lesser value.

II. NEED FOR REUSE OF PLASTIC WASTE

Plastic waste is global concern and India is no exception to it, the plastic uses in various states are getting used in goof quantity and recently initiatives are being taken to ban the plastic in cities/states in few part of country. However 100% ban will be still far from reality. Alternatively recycle and reuse is another area where more focus is drawn because of various reasons shown below:

1) Disposal of waste plastic is a major problem
2) It is non-biodegradable
3) Burning of these waste plastic bags causes environmental pollution.
4) It mainly consists of low-density polyethylene
5) To find its utility in bituminous mixes for road construction

Laboratory performance studies were conducted on bituminous mixes. Laboratory studies proved that waste plastic enhances the property of the mix and improvement in properties of bituminous mix provides the solution for disposal in a useful way

Type of plastic waste

Categorization of plastic waste is generally done on the basis of their origin. The detailed summary of type of plastic waste is given in table 1 below

TABLE 1: Type of plastic waste

Various type of waste plastic (polymer)	Origin
Low density polyethylene (LDPE)	bags, sacks, bin lining and squeezable detergent bottles etc
High density polyethylene (HDPE):	bottles of pharmaceuticals, disinfectants, milk, fruit juices, bottle caps etc
Polypropylene (PP)	bottle cap and closures, film wrapping for biscuits, microwave trays for ready-made Meals etc.
Polystyrene (PS)	yoghurt pots, clear egg packs, bottle caps
Foamed Polystyrene	food trays, egg boxes, disposable cups, protective packaging etc
Polyvinyl Chloride (PVC)	mineral water bottles, credit cards, toys, pipes and gutters; electrical fittings, furniture, folders and pens; medical disposables; etc

III. LABORATORY STUDIES FOR USE OF WASTE PLASTIC IN BITUMINOUS CONCRETE MIXES

The below section on job mix formula for 40mm bituminous concrete is obtained and optimum modifier (i.e. waste plastic) content is obtained by Marshall mix design method. Bituminous concrete construction is used for wearing courses and profile corrective courses. As per Ministry of Road Transport and Highways (MORTH, 2001) this work shall consist of construction in a single or multiple layers of bituminous concrete on a previously prepared bituminous bound surface and a single layer should be of 25mm to 65mm thick. Bituminous concrete construction is selected for the study as most of the work done within the Jaipur and nearby territory is already in use for this type of construction. Though, this study can also be experimented on other layers like dense graded bituminous macadam and semi-dense bituminous concrete also.

Methodology- In India, bituminous concrete mix is commonly designed by Marshall Method. ASTM and other agencies have standardized the test procedure. This stability test is applicable to hot mix design of bitumen and aggregates with maximum size of 2.5 cm.

Mix design by Marshall Methods

Purpose - The purpose of the mix design is to determine an economical blend of aggregate and bitumen to provide a mix of the required properties.

Procedure -The aggregate grading and the design criteria should be selected for the anticipated conditions-of traffic, climate, etc.

Properties of material used for bituminous concrete mix

Material used for B.C. mixes are generally aggregates, bitumen and additives. In present case additive is waste plastic bags in shredded form.

Aggregates- Aggregates used in the present study were first tested for physical properties and results are shown in table 2

TABLE 2 – Physical properties of aggregates

Sr. No	Test Description	Test Method	Result
1	Specific gravity of 11.2mm grit	IS:2386 (Pt. IV – 1963)	2.53
2	Specific gravity of 6.7mm grit	IS:2386 (Pt. IV – 1963)	2.53
3	Water Absorption (%)	IS:2386 (Pt. III – 1963)	0.75
4	Specific gravity of stone dust	IS:2386 (Pt. IV – 1963)	2.55
5	Impact Value (%)	IS:2386 (Pt. IV – 1963)	23.49
6	Stripping Value (%)	IS:2386 (Pt. IV – 1963)	0.0

Bitumen

Bitumen grade 60/70 is been used for the present study. The properties of bitumen are shown in table 3 below:

TABLE 3 – Properties of bitumen

S. No.	Test Description	Test Method	Results
1	Ductility at 27^{o} C (cm)	IS – 1208 – 1978	90
2	Specific gravity	IS – 1208 – 1978	1.00
3	Penetration test (100gm, 5 seconds at 25^{o} C) (1/10th of mm)	IS – 1208 – 1978	70

Waste Plastic

Waste plastic in shredded form is used in present study as a modifier of the bituminous concrete mix. The specific gravity of the modifier was found to be 1.03. Plastic bags used for present study were size of 2mm (approximate). According to literature the melting temperature was 75 to 138^{o} C, and there was no weight loss up to 200^{o} C and approximately 6% weight loss was observed in the temperature range between 200^{o} C to 400^{o} C due to oxidative degradation. From these results it is concluded that the modifier can be used safely up to 200^{o} C in the bituminous mixes. The modifier can be added into the heated aggregates just before mixing the bitumen at the optimum binder content.

Design of bituminous concrete mixes

The Marshall method of mix design is used for obtaining optimum binder content and optimum modifier (waste plastic) content.

Gradation Test for 40mm thick bituminous concrete

The individual gradation results for 11.2mm size grit, 6.7mm grit and stone dust are given in table 4

TABLE 4 – Combined gradation results

JOB grading obtained by mixing 11.2mm grit 35%, 6.7mm grit 30% and stone dust 35%					
Sieve Size (mm)	35% 11.2mm Grit	30% of 6.7mm Grit	35% of Stone Dust	Total	Requirement as per MORTH
19.0	35	30	35	100	100
13.2	34.055	30	35	99.055	79 - 100
9.5	18.48	30	35	83.48	72 - 88
4.75	8.715	22.8	35	66.515	53 - 71
2.36	5.222	12.6	35	52.822	42 - 58
1.18	1.302	8.4	30.73	40.432	34 - 48
0.6	0.952	6.66	26.32	33.932	26 - 38
0.3	0.777	5.28	17.885	23.942	18 - 28
0.15	0.609	3.216	13.44	17.265	12 - 20
0.075	0.532	2.676	4.9	8.108	4 - 10

Marshall Stability Test

This method covers the measurement of the resistance to plastic flow of cylindrical specimen of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. This method is for use with hot mixtures Containing bitumen or tar and aggregate up to 1 in. maximum size. The reference is taken from A.S.T.M. D 1559 – 62T.

Observation taken during Marshall Stability test is shown in table 5

TABLE 5 – Marshall Stability

Bitumen %age in A.C. Mix (%)	Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
							Division	Load Factor	Co-relation Ratio	
4.5	I	1180	644	536	2.20	2.26	121	6.74	0.93	758.45
	II	1175	639	536	2.19	2.22	120	6.74	0.93	752.18
	III	1170	636	534	2.19	2.2	118	6.74	0.93	739.65
	Average				**2.195**	**2.227**				**750.09**
5.0	I	1185	651	534	2.22	2.5	135	6.74	0.96	873.50
	II	1190	656	534	2.23	2.52	137	6.74	0.96	886.44
	III	1184	651	533	2.22	2.48	134	6.74	0.96	867.03
	Average				**2.223**	**2.5**				**875.66**
5.5	I	1182	657	525	2.25	2.8	147	6.74	0.96	951.14
	II	1180	658	522	2.26	2.75	146	6.74	1	984.04
	III	1175	653	522	2.25	2.7	143	6.74	1	963.82
	Average				**2.254**	**2.75**				**966.33**
6.0	I	1188	660	528	2.25	3	151	6.74	0.96	977.03
	II	1190	661	529	2.25	3.1	152	6.74	0.96	983.50
	III	1178	657	521	2.26	2.9	146	6.74	1	984.04
	Average				**2.254**	**3**				**981.52**
6.5	I	1184	653	531	2.23	3.3	131	6.74	0.96	847.62
	II	1178	652	526	2.24	3.5	135	6.74	0.96	873.50
	III	1180	651	529	2.23	3.2	128	6.74	0.96	828.21
	Average				**2.233**	**3.333**				**849.77**

Calculation of binder content

Calculation of Specific Gravity of Mineral Aggregates (SGMA)				
1	Formula	100 / ((W1/G1) + (W2/G2) + (W3/G3))		
	Where	W1	%age weight of 11.2mm grit	35%
		W2	%age weight of 6.7mm grit	30%
		W3	%age weight of stone dust	35%
		G1	Specific gravity of 11.2mm grit	2.53
		G2	Specific gravity of 6.7mm grit	2.53
		G3	Specific gravity of stone dust	2.55
	Result (SGMA)			2.54

Specific Gravity of Mix (SGM)			
2	Formula	(100 + B) / ((100/SGMA) + (B/G_B))	
	Where	B	%age of bitumen
		G_B	Specific gravity of bitumen

Calculation of Specific Gravity of Mix (SGM)						
B	SGMA	G_B	(100+B)	(100/SGMA)	(B/G_B)	SGM
4.5	2.54	1	104.5	39.37	4.5	2.38
5	2.54	1	105	39.37	5	2.37
5.5	2.54	1	105.5	39.37	5.5	2.35
6	2.54	1	106	39.37	6	2.34
6.5	2.54	1	106.5	39.37	6.5	2.32

Compacted Density of Mineral Aggregates (CDMA)			
3	Formula	CDM / (1 + B / 100)	
	Where	B	%age of bitumen
		CDM	Compacted density of mix

B	CDM	B/100	CDMA (gm per cc)
4.5	2.19	0.045	2.096
5	2.22	0.05	2.114
5.5	2.25	0.055	2.133
6	2.25	0.06	2.123
6.5	2.23	0.065	2.094

Voids in Mix (VIM)			
4	Formula	((SGM - CDM) / SGM) * 100	
	Where	SGM	Specific Gravity of Mix
		CDM	Compacted density of mix

B	CDM	SGM	VIM (Percentage)
4.5	2.19	2.38	7.98
5	2.22	2.36	5.93
5.5	2.25	2.35	4.26
6	2.25	2.33	3.43
6.5	2.23	2.32	3.88

Voids in Mineral Aggregates (VMA)			
5	Formula	((SGMA - CDMA) / SGMA) * 100	
	Where	SGMA	Specific Gravity of Mineral Aggregates
		CDMA	Compacted density of Mineral Aggregates

B	CDMA	SGMA	VMA (Percentage)
4.5	2.09	2.54	17.72
5	2.11	2.54	16.93
5.5	2.13	2.54	16.14
6	2.12	2.54	16.54
6.5	2.09	2.54	17.72

Voids Filled by Bitumen (VFB)			
6	Formula	((VMA - VIM) / VMA) * 100	
	Where	VMA	Voids in Mineral Aggregates
		VIM	Voids in Mix

B	VMA	VIM	VFB (Percentage)
4.5	17.72	7.98	54.97
5	16.93	5.93	64.97
5.5	16.14	4.25	73.67
6	16.54	3.43	79.26
6.5	17.72	3.87	78.16

The various graphs are prepared based on the calculation done.

Figure 1: Bitumen Content v/s Compacted Density of Mix

Compacted density of Mix

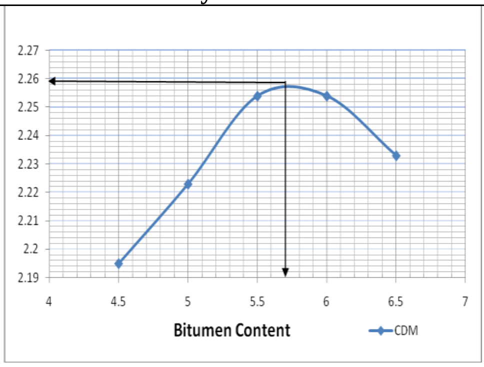


Figure 2: Bitumen Content v/s Voids in Mix

voids in Mix

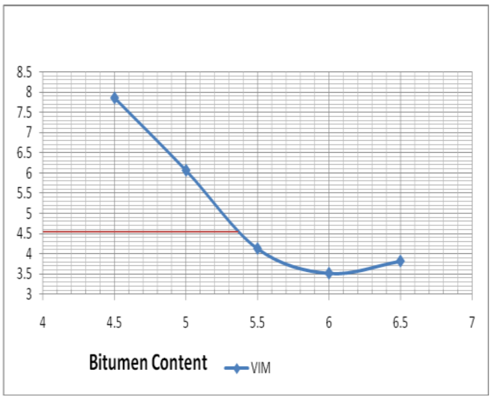


Figure 3: Bitumen Content v/s Stability

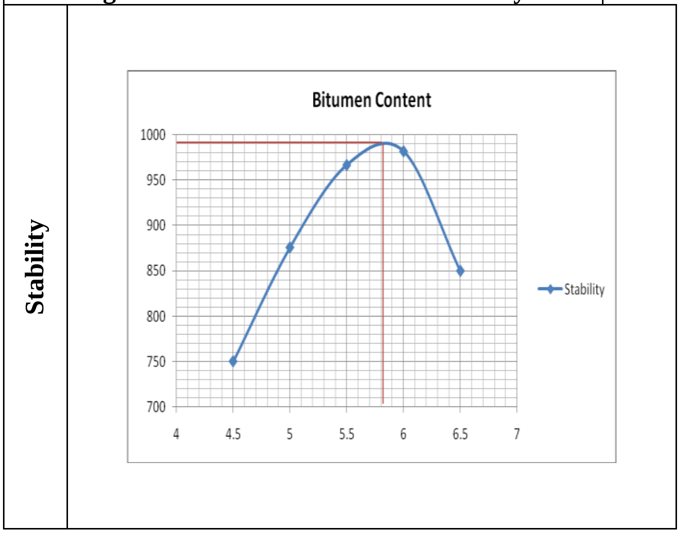


Figure 4: Bitumen Content v/s Voids filled with bitumen

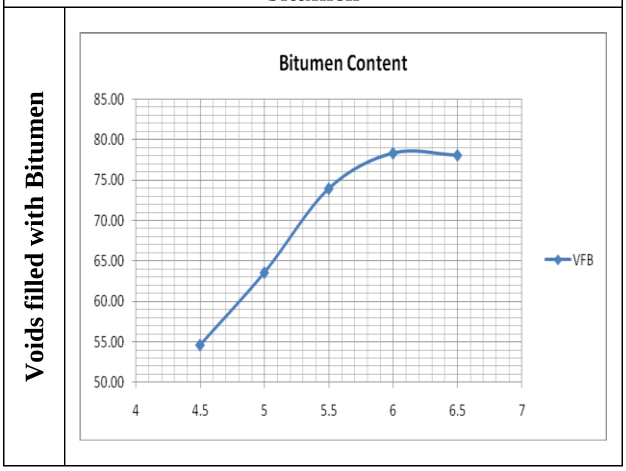
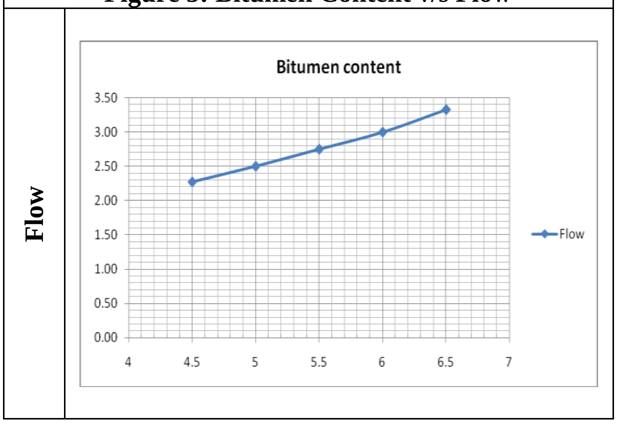


Figure 5: Bitumen Content v/s Flow



From figure 1, figure 2 and figure 3,
Maximum CDM found at 5.75% bitumen
Maximum stability found at 5.825% bitumen
Median VIM (range 3-6%) found is 5.425%
The average binder content value is = (5.75+5.825+5.425) / 3 = 5.66 i.e. (5.7%)
The recommended optimum binder content is 5.7%

Properties of conventional bituminous concrete mix are tabulated below in table 3.8:

TABLE 6 – Properties of conventional bituminous concrete mix

Property	Binder content by weights of aggregates (%)				
	4.5	5.0	5.5	6.0	6.5
Marshall Stability (Kgs)	750.095	875.66	966.336	981.52	849.77
Compacted density of mix	2.19	2.22	2.25	2.25	2.23
Flow value (mm)	2.22	2.48	2.7	3.0	3.3
Air Voids (%)	7.98	5.93	4.26	3.43	3.88
Voids filled with bitumen (VFB %)	54.97	64.97	73.67	79.26	78.16
Voids in mineral aggregates (VMA %)	17.72	16.93	16.14	16.54	17.72
Optimum Binder Content	5.7				

In next step waste plastic were added by varying the proportion from 2 to 12 percent by weight of bitumen with an increment of 2 percent (2, 4, 6, 8, 10 & 12). The modifier (waste plastic in shredded form) was added in to the heated aggregates (heating temperature 80o to 100o C) just before mixing the bitumen at the optimum 5.7 percent binder content.

Optimum plastic content

Marshall Method of mix design is shown in tables for determining optimum plastic content. Maximum value of stability was considered as criteria for optimum waste plastic content.

a) Marshall test results with 5.7 % binder content and 2% waste plastic are shown in table 7 below

TABLE 7: 5.7% binder content with 2% waste plastic

Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
						Division	Load Factor	Co-relation ratio	
I	1188	659	529	2.25	2.82	157	6.74	0.96	1015.9
II	1190	662	528	2.25	2.76	158	6.74	0.96	1022.3
III	1185	657	528	2.24	2.74	156	6.74	0.96	1009.4
Average				**2.248**	**2.773**				**1015.85**

b) Marshall test results with 5.7 % binder content and 4% waste plastic are shown in table 8 below

TABLE 8: 5.7% binder content with 4% waste plastic

Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
						Division	Load Factor	Co-relation Ratio	
I	1186	656	530	2.24	3.1	161	6.74	0.96	1041.7
II	1184	655	529	2.24	3	162	6.74	0.96	1048.2
III	1188	659	529	2.25	3	162	6.74	0.96	1048.2
Average				**2.241**	**3.033**				**1046.05**

c) Marshall test results with 5.7 % binder content and 6% waste plastic are shown in table 9 below

TABLE 9: 5.7% binder content with 6% waste plastic

Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
						Division	Load Factor	Co-relation ratio	
I	1190	656	534	2.23	3.1	172	6.74	0.96	1112.9
II	1193	657	536	2.23	3.2	173	6.74	0.93	1084.4
III	1192	655	537	2.22	3.2	174	6.74	0.93	1090.7
Average				**2.225**	**3.167**				**1095.99**

d) Marshall test results with 5.7 % binder content and 8% waste plastic are shown in table 10

TABLE 10: 5.7% binder content with 8% waste plastic

Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
						Division	Load Factor	Co-relation Ratio	
I	1193	655	538	2.22	3.2	189	6.74	0.93	1184.7
II	1192	657	535	2.23	3.1	186	6.74	0.96	1203.5
III	1194	656	538	2.22	3.2	188	6.74	0.93	1178.4
Average				**2.222**	**3.167**				**1188.87**

e) Marshall test results with 5.7 % binder content and 10% waste plastic are shown in table 11 below

TABLE 11: 5.7% binder content with 10% waste plastic

Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
						Division	Load Factor	Co-relation Ratio	
I	1188	650	538	2.21	3.4	152	6.74	0.93	952.8
II	1190	651	539	2.21	3.3	151	6.74	0.93	946.5
III	1192	655	537	2.22	3.2	156	6.74	0.93	977.8
Average				**2.212**	**3.300**				**959.03**

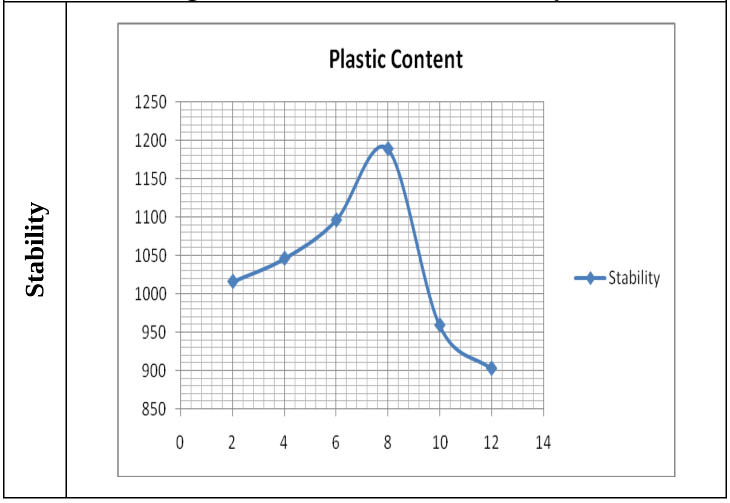
f) Marshall test results with 5.7 % binder content and 12% waste plastic are shown in table 12

TABLE 12: 5.7% binder content with 12% waste plastic

Identification Mark	Weight of Asphaltic concrete mould in air (gm)	Weight of Asphaltic concrete mould in water (gm)	Volume of mould (cc)	Asphaltic mould C.D.M. (g/cc)	Flow Value	Dial Gauge reading			Marshall Stability (Kgs)
						Division	Load Factor	Co-relation Ratio	
I	1190	651	539	2.21	2.52	144	6.74	0.93	902.6
II	1186	646	540	2.20	2.5	143	6.74	0.93	896.4
III	1185	646	539	2.20	2.5	145	6.74	0.93	908.9
Average				**2.201**	**2.507**				**902.62**

Based on above results (derived from Table 7 to Table 12) the graph is plotted between plastic contents and stability

Figure 6: Waste Plastic v/s Stability



From the Table 3.10 the compacted density of mix at 8% plastic is found as 2.222 gm/cc.

From figure 6, it was found that the optimum modifier (waste plastic) content was 8% by weight of bitumen.

CONCLUSIONS

The durability of the roads laid out with shredded plastic waste is much more compared with roads with asphalt with the ordinary mix. Roads laid with plastic waste mix are found to be better than the conventional ones. The binding property of plastic makes the road last longer besides giving added strength to withstand more loads. While a normal 'highway quality' road lasts four to five years it is claimed that plastic-bitumen roads can last up to 10 years. Rainwater will not seep through because of the plastic in the tar. So, this technology will result in lesser road repairs. And as each km of road with an average width requires over two tones of poly blend, using plastic will help reduce non-biodegradable waste. The cost of plastic road construction may be slightly higher compared to the conventional method.

Based on the study it can be concluded that binder content for bituminous concrete without plastic waste is determined as 5.7% and by mixing 8% plastic waste (of binder content) properties of conventional bituminous concrete are modified. With 8% waste plastic in 5.7% optimum binder content the mixed design values were compared.

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