UTILIZATION OF WASTE PLASTIC IN FLEXIBLE PAVEMENTS

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Abstract - *Plastics are non-biodegradable materials and their omnipresence degrades our environment. The waste plastic and its disposal cause environmental pollution and global warming. Plastic waste can be used in flexible pavements by enhancing the bitumen properties and strength. Various defects in Road Pavements i.e., pot holes, corrugation, ruts, etc. can be remedied using waste plastic in the form poly-ethylene and poly-propylene. A series of tests were performed on the bitumen with conventional and plastic mix with 4%, 5% and 6% of Binder content. The Marshall method of mix design is used for the determination of optimum bitumen content. It is further used for the design of flexible bituminous pavement using VG-30 grade of bitumen. The Results of plastic mix has shown an increase in its stability value when compared with conventional mix. From the results, 5% binder content has the maximum stability value. Hence, it is considered as the optimum bitumen content for the design of flexible pavements.*

Key Words**:** Marshall stability, bituminous mix, non-biodegradable, waste plastic, flexible pavement, optimum bitumen content, binder, stability.

1.INTRODUCTION

Plastics are non-biodegradable materials and their omnipresence degrades our environment. The waste plastic and its disposal cause environmental pollution and global warming. Plastics are a wide range of synthetic or semi-synthetic materials that use polymers as a main ingredient. Their plasticity makes it possible for plastics to be moulded, extruded or pressed into solid objects of various shapes. This adaptability, plus a wide range of other properties, such as being lightweight, durable, flexible, and inexpensive to produce, has led to its widespread use. Plastic can be divided into two categories- thermoplastics & thermosetting plastics. Thermoplastics have high durability, resists humidity and other harsh environments, no chemical reaction occur during application processing. Therefore, can be primarily used in the pavement construction. Researches have showed that plastic can be used for the construction of bituminous roads as well, in fact Plastics used are high-density polyethylene, polypropylene since, they are inexpensive and exhibit high flexural strength and resistance to moisture. Generally, Pavement failures occur due to insufficient quality of materials or inadequate drainage and the water seeps into the pavement layers, makes the material loose and that creates potholes and many other failures. Plastics when used in pavements produces high stability, good binding property and does not allow water to seep through it and thus becomes a solution for many pavement failures. According to the Guidelines on use of Plastic Waste in Road Construction by Ministry of railways, waste plastic of 6 to 8 percent of the weight of bitumen is used for bituminous concrete. Marshall stability tests were performed on the mix with varying proportion of bitumen to compare the results without plastic and to determine the optimum bitumen content.

1.1 Objectives

1) To utilize the plastic waste in construction and reduce its impact on environment.
2) To evaluate the optimum bitumen content.
3) To analyze and compare the performance tests like Marshall stability value for conventional bituminous mix and modified bituminous mix.

1.2 Scope of work

This study mainly focuses on increasing the strength of pavement so that it can increase the life span of the flexible pavement however main scope of current project work are:

- To eradicate the pavement failures.
- To minimize the plastic waste impact on the environment.
- To reduce the maintenance cost of the road.
- To increase the stability of bituminous concrete.

2. LITERATURE REVIEW

1.Partial replacement of bitumen with plastic waste in flexible pavements (IRJET) ISSN: 2395-0056 Volume-7 Issue-7 **[U. Sathish, A. V. Sandeep, K. Shyam Kumar, V. Hari Gopal, K. Hari Krishna and J. Asha Jyothi, 2020] 2.** The design of Flexible Pavement using plastic waste **[Devesh ojha et al, 2014] 3.** Experimental Investigation of Plastic-Coated Aggregate (IJERT) ISSN: 2278-0181 Special Issue-2021 **[Yogita Bhiva Alave, Sanika Shekhar Mahimkar,**

Ketki Sanjay Patil, Jayprakash Jiyala Gupta, Arbaz Kazi, 2021] 4. Use of Plastic Waste in Flexible Pavement-Green Highway (IJERT) ISSN:2278-0181 Volume-9 Issue-9 **[Prashant Singh, Abhishek Kumar, Shushant Singh, Rajeev Rajput, Chhabi Lal Singh, 2020] 5.** An approach to the usage of polyethylene terephthalate (PET) waste as roadway pavement material. **[Metin Guru, M. Kursat Cubuk, Deniz Arslan, S. Ali Farzanian, Ibrahim Bilici, 2014] 6.** An Overview on Waste Plastic Utilization in Asphalting of Roads ISSN: 0976-7916 **[Amit Gawande, G. Zamare, V.C. Renge, Saurabh Tayde, G. Bharsakale]**

3. MATERIALS AND METHODOLOGY

A. Materials Used:

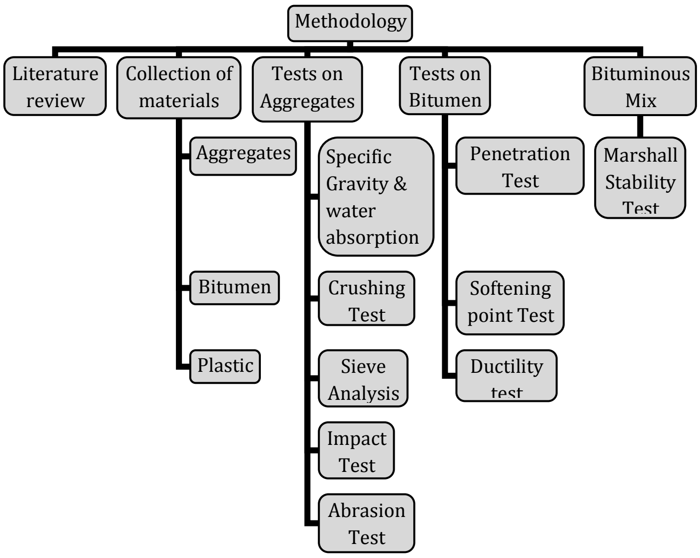
1. Aggregates of size 20mm-2.36mm
2. Bitumen of VG-30 category
3. Cement (filler)
4. Plastic waste
   - High density polyethylene
   - Polypropylene

Plastic used is collected from the waste plastic items such as buckets, jars, bags, covers, bottles,...etc. This collected waste is shredded into pieces of size 10-20mm with the help of plastic shredding machine. According to "Guidelines on use of Plastic Waste in Road Construction" by ministry of railways, waste plastic of 6 to 8 % of weight of bitumen is used for bituminous concrete.

Fig-1 Shredded waste plastic

B. Methodology:

The methodology is the general research stratergy that outlines the way in which research is to be undertaken and, among other things, identifies the methods to be used in it. A proper organized research plan is required to complete a project with the deadlines and to reach to a conclusion. It begins from the procurement of materials, conducting preliminary tests on the aggregates and bitumen. Experimental investigation of aggregate includes various tests like crushing, impact, abrasion…etc. and the plastic used is polyethylene, polypropylene shredded into pieces and mixed along with the hot bituminous mix. This bituminous mix undergoes marshall stability test and the results were compared with conventional mix to obtain the optimum bitumen content is the process involved in our methodology. The proposed methodology chart of the project is shown below:



3.1 Tests on Aggregate

1. Crushing test

The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The test is standardized by IS:2386 part-IV

Table No.: 1 Summary of Crushing Test on Aggregate

SNO	Observation	Readings
1	Total weight of dry sample(W_1) in gm	2890
2	Weight of fines passing 2.36mm sieve (W_2) in gm	730
3	Aggregate crushing value= W_2/W_1*100	25.25

2. Impact test

It is the ability of aggregates that resist sudden impact or shock load on it. The Aggregate impact test is carried out to evaluate the resistance to impact of aggregates. The test is standardized by IS:2386 part-IV 1963

Table No.: 2 Summary of Impact Test on Aggregate

SNO.	Observation	Readings
1	Total weight of aggregate sample filling cylindrical measure (W_1) kg	0.35
2	Weight of aggregate passing through 2.36mm IS sieve (W_2)	0.034
3	Aggregate impact value= $(W_2/W_1)*100$	9.71

3. Specific Gravity & water absorption test

The specific gravity is usually showed the strength and quality of the material. This test is standardized by IS:2386 part 3-1963

Table No.: 3 Summary of specific gravity test on aggregate

SNO.	Observation	
1	Weight of empty bottle (W_1) kg	0.570
2	Weight of the bottle and aggregate (W_2) kg	1.360
3	Weight of the bottle + aggregate + water (W_3)	1.960
4	Weight of the bottle + water (W_4) kg	1.455
5	Specific gravity, G_s	2.77

Water absorption of aggregates is the % of water absorbed by an air-dried aggregate when immersed in water at 27°C for a period of 24 hours. This test is standardized by IS:2386 part 3-1963.

Table No.: 4 Summary of water absorption test on aggregate

SNO	Observation	
1	Weight of wet aggregates (W_1) gm	20
2	Weight of oven dried aggregates (W_2)	15
3	Water content= $(W_1-W_2/W_2)*100$	33.3%

4. Abrasion Test

Abrasion test is the measure of aggregate toughness and abrasion resistance such as crushing, degradation and disintegration. The abrasion test of aggregate is done as per IS:2386 part 4-1963.

Table No.: 5 Summary of abrasion test on aggregate

SNO	Observation	
1	Original weight of aggregate (W_1) in gm	5000
2	Weight of sample retained on 1.7mm IS sieve (W_2) in gm	4060
3	Loss in weight due to wear (W_1-W_2) gm	940
3	Abrasion value= $(W_2-W_1)/W_1$ *100	18.80%

5. Sieve Analysis

The Sieve analysis of coarse aggregate test indicates the size distribution of coarse aggregate particles in a given coarse aggregate sample. The fineness modulus is the indication of the mean size of the particles. The fineness modulus is used to grade the given aggregate. This is done as per IS:383-1970.

Fineness modulus of aggregate = 6.3

3.2 Tests on Bitumen

1. Penetration Test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. It is done in accordance with IS:1203-1978.

2. Ductility Test

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. This test was carried out in accordance with IS:208-1978.

3. Softening Test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted in accordance with IS:1205-1978.

The Summary of results obtained of the various test mentioned above is shown in the table below:

Table No.:6 Summary of Test Results Conducted on Bitumen

Test on VG30 Bitumen	Test Result on VG30 Bitumen	VG30 Standard Results
Penetration at 25° C	30-60	60
Softening point ° C, min	55	56
Ductility at 25° C, cm, min	49.4	68

3.3 Marshall Stability Test

The detailed procedure of finding stability and Flow of the bitumen using marshal stability test as per IRC 111:2009 is presented below:

Requirements:

- Cylinder: Día =101.6mm, Height =63.5mm
- Hammer
- MST load application machine
- Weighing machine
- Specimen extractor
- Water bath
- Oven

Preparation of Test Specimen

1. 1200 grams of aggregate blended in the desired proportions is measured and heated in the oven to the mixing temperature.
2. Bitumen is added at the mixing temperature to produce viscosity of 170 ± centi-stokes at various percentages.
3. The materials are mixed in a heated pan with heated mixing tools.
4. The mixture is returned to the oven and reheated to the compacting temperature (to produce viscosity of 280±30 centi-stokes).
5. The mixture is then placed in a heated Marshall mould with a collar and base and the mixture is spaded around the sides of the mould. A filter paper is placed under the sample and on top of the sample.
6. The mould is placed in the Marshall Compaction pedestal.
7. The material is compacted with 75 blows of the hammer, and the sample is inverted and compacted in the other face with same number of blows.
8. After compaction, the mould is inverted. With collar on the bottom, the base is removed and the sample is extracted by pushing it out the extractor.
9. The sample is allowed to stand for the few hours to cool.
10. The mass of the sample in air and when submerged is used to measure the density of specimen, so as to allow, calculation of the void properties.

Marshall Test Procedure

1. Specimens are heated to 60 ± 1 °C either in a water bath for 30 - 40 minutes or in an oven for minimum of 2 hours.
2. The specimens are removed from the water bath or oven and place in lower segment of the breaking head. The upper segment of the breaking head of the specimen is placed in position and the complete assembly is placed in position on the testing machine.
3. The flow meter is placed over one of the posts and is adjusted to read zero.
4. Load is applied at a rate of 50 mm per minute until the maximum load reading is obtained.
5. The maximum load reading in Newton is observed. At the same instant the flow as recorded on the flow meter in units of mm was also noted.
6. Marshall stability value = Initial Marshall stability value * correction factor

Average Thickness of specimen, mm	Correction Factor
57.2	1.19
58.7	1.14
60.3	1.09
61.9	1.04
63.5	1.00
65.1	0.96
66.7	0.93
68.3	0.89
69.8	0.86

Table No.: 7 Correction factor for Marshall stability test

3.4 Conclusion for Aggregate and Bitumen Tests

The various tests on Aggregates have shown favorable results and they are proven to be strong according to the codal recommendations. Apart the bitumen obtained from the source is VG30 which is being confirmed by comparing results with IS standards.

3.5 Conclusion for Marshall stability Test

Marshall stability test is conducted on 4%, 5% and 6% bitumen content, 3 specimens were prepared for each percentage and tested. The test is done on conventional samples without plastic and same process is repeated by adding 8% of plastic to the weight of binder content. The results of stability and flow values were compared.

4. RESULTS AND DISCUSSION

After evaluating the results of marshal stability test, the next step was to find the properties of the mix like bulk specific gravity, percent air voids…etc. These properties should be calculated for each specimen and results were verified to obtain the optimum bitumen content. The parameters obtained for 5% bituminous mix are shown below, similar steps were done finding parameters of other remaining contents with and without plastic.

Weight of sample in air (W_a) = 1150 gm

Weight of sample in water (W_w) = 690 gm

Weight of coarse aggregate (W_1) = 1200 gm

Weight of filler (W_2) = 48 gm

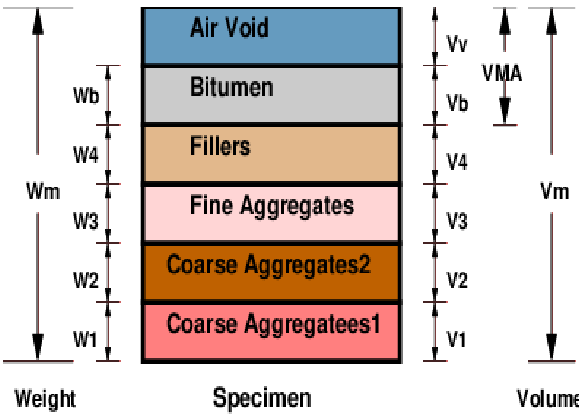
Weight of bitumen (W_b) = 60 gm

Specific gravity of coarse aggregate (G_1) = 2.77

Specific gravity of filler (G_2) = 3.1

Specific gravity of bitumen (G_b) = 1.01

Fig-2 Phase diagram of a bituminous mix



1. Theoretical specific gravity of the mix (G_t)

$$G_t = \frac{W_1 + W_2 + W_b}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_b}{G_b}}$$

$$= \frac{1200+48+60}{1200/2.77 + 48/3.1 + 60/1.01}$$

$$= 2.57$$

2. Bulk specific gravity of the mix (G_{mb})

$$G_m = \frac{W_m}{W_m - W_w}$$

$$= \frac{1150}{1150-690}$$

$$= 2.5$$

3. Percentage air voids (V_v)

$$V_v = \frac{(G_t - G_m)\,100}{G_t}$$

$$= \frac{(2.57-2.5)100}{2.57}$$

$$= 2.72\ \%$$

4. Percent volume of bitumen (V_b)

$$V_b = \frac{\frac{W_b}{Gb}}{\frac{W_1 + W_2 + W_b}{G_m}}$$

$$= \frac{60}{1.01} \times \frac{2.5}{1308}$$

= 11.3 %

5. Voids in mineral aggregate (VMA)

$$VMA = V_V + V_b$$

$$= 2.72 + 11.3$$

$$= 14.02\ \%$$

6. Voids filled with bitumen (VFB)

$$VFB = \frac{V_b * 100}{VMA}$$

$$= \frac{11.3}{14.02} \times 100$$

$$= 80.59\ \%$$

The same procedure is applied to calculate the properties of plastic mix by considering weight and specific gravity of the plastic also. The results were shown in Table-11

The average is calculated from the results of 3 specimens for each percentage and represented in the table below.

Table No.: 8 Results of Marshall stability test for nominal mix

Bitumen content (%)	Height of specimen (mm)	Weight of specimen (gm)			Bulk sp.gr. of mix (G_m)	Marshall stability (kg)
		Air	Water	SSD		
4%	70	1220	703	1255	2.39	2891
5%	65	1150	690	1200	2.46	3204
6%	69	1250	742	1270	2.42	2288

Table No.: 9 Results of Marshall stability test for plastic mix

Bitumen content (%)	Height of specimen (mm)	Weight of specimen (gm)			Bulk sp.gr. of mix (G_m)	Marshall stability (kg)
		Air	Water	SSD		
4%	69	1205	725	1255	2.47	3051
5%	70	1160	690	1200	2.45	3351
6%	73	1270	752	1300	2.43	2385

4.1 Parameters for obtaining the optimum bitumen content

The Marshall stability value gradually rises with the increase in binder content up to a certain point and then decreases gradually. That maximum stability value is noted and to be considered for obtaining the optimum bitumen content.

Table No.: 10 Parameters for obtaining the optimum bitumen content of nominal mix

Bitumen content	Air void (V_V) %	Stability value (kg)	Density (g/cc)	Flow value (mm)	VMA %	VFB %
4%	8.19	2891	2.39	2.33	17.0	53.1
5%	3.9	3204	2.46	4.33	15.1	74.3
6%	4.19	2288	2.42	3.00	17.2	76.4

Table No.: 11 Parameters for obtaining the optimum bitumen content of plastic mix

Bitumen content	Air void (V_V) %	Stability value (kg)	Density (g/cc)	Flow value (mm)	VMA %	VFB %
4%	4.37	3051	2.47	4.66	13.4	67.7
5%	3.65	3351	2.45	4	14.8	75.1
6%	3.3	2385	2.43	3.66	16.4	80.1

4.2 Results of Marshall stability Test

Following graphs show the variation in test with the variation in bitumen and also the comparison of different properties of nominal and plastic bituminous mix.

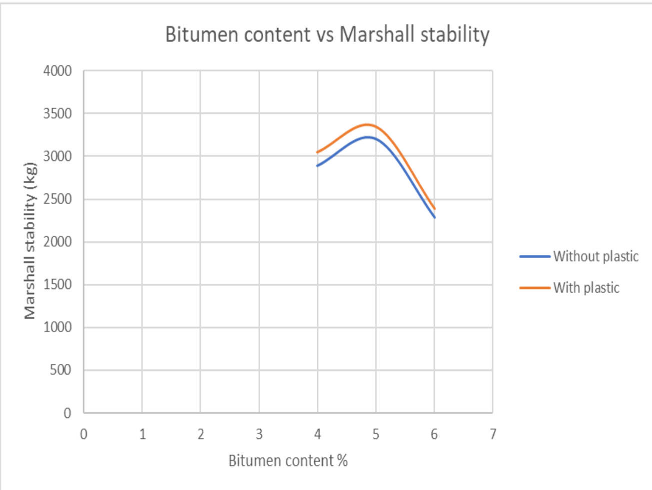


Fig No-3 Bitumen content vs Marshall stability

Fig-3 shows the variation in Marshall stability with percentage of bitumen where it is seen that 5% bitumen content gave the higher stability value and also the stability increased comparatively in the plastic mix.

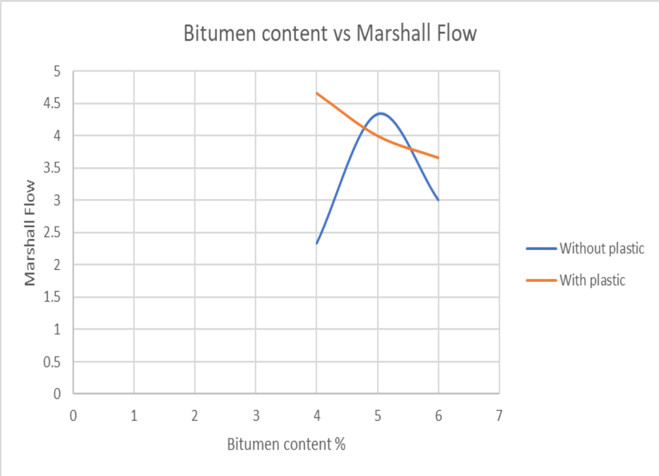


Fig No-4 Bitumen content vs Marshall flow

Fig-4 shows the variation in Marshall flow with percentage of bitumen where it is seen that flow value is increased in plastic when compared with conventional bituminous mix.

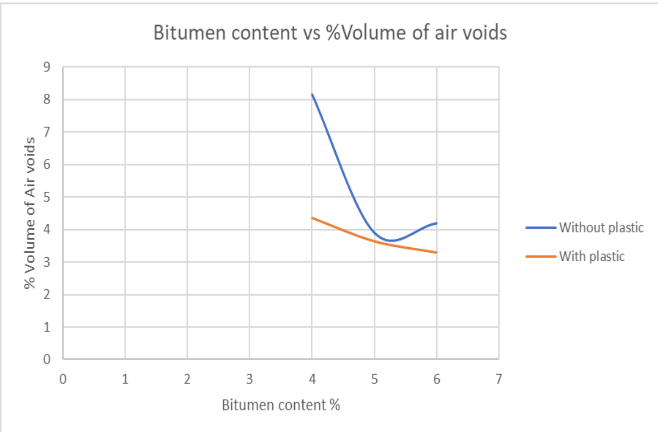


Fig No-5 Bitumen content vs Volume of air voids

Fig-5 shows the variation in volume of air voids with percentage of bitumen where it is seen a gradual reduction of air voids with increase in bitumen.

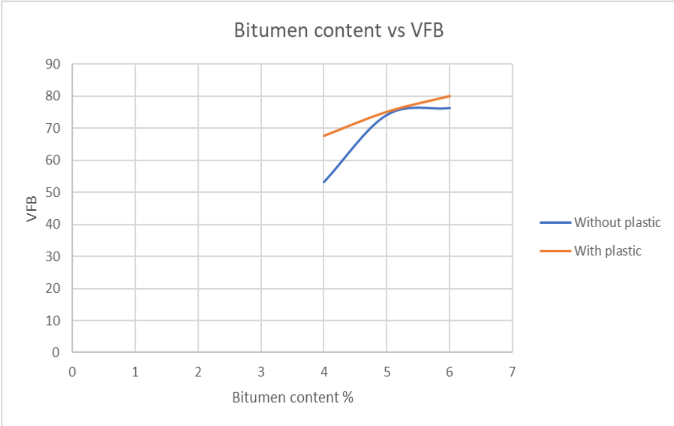


Fig No-6 Bitumen content vs VFB

Fig-6 shows the variation in Voids filled with bitumen (VFB) with percentage of bitumen where it is seen an increase in the VFB with increasing the bitumen content.

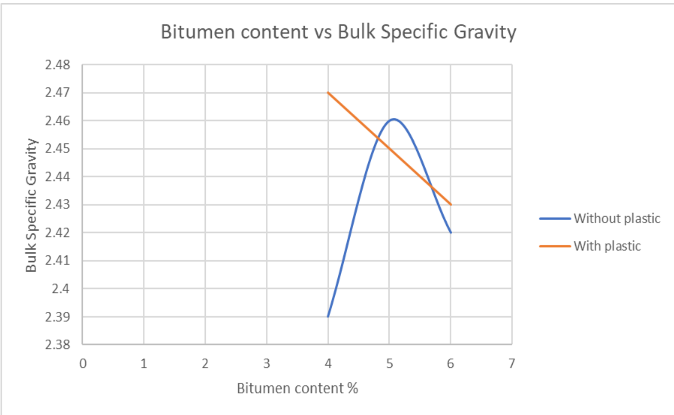


Fig No-7 Bitumen content vs Bulk specific gravity

Fig-7 shows the variation in bulk specific gravity with bitumen content where it seen that usually a decreasing trend is followed with increase in bitumen content.

4.3 Determination of optimum bitumen content

To determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found from the graphs obtained in the previous step.

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity (G_m)
3. Binder content corresponding to the median of designed limits of percent air voids (V_v) in the total mix.

Optimum bitumen content =

(5+5+5) / 3 = 5 %

Here the mix has higher properties at 5% bitumen content in both nominal and plastic mix also. The stability value is increased in addition of plastic. After finding the optimum bitumen content for the design mix, next step is to check the stability value, flow value, and VFB with Marshall mix design specification chart given in Table below.

Table No.: 11 IRC 94-1966 Specification

Test property	Specified value	Obtained value
Marshall stability (kg) minimum	340	3351
Flow value, 0.25mm units	8-17	4
percent air voids in the mix (Vv) %	3-5	3.65
Voids filled with bitumen	75-85	75.13

4. CONCLUSIONS

1. Recycled plastic along with aggregates is used for better performance of roads. Usage of waste plastic in the bituminous concrete increased the stability so that the load carrying capacity of the road will also get increased.

2. Plastic when mixed with the hot bituminous mix it gets softened and acts as a good binder. Thus, permeability reduces which means that the mixture becomes more intact thus providing a solution up to some extent for stagnation of water.

3. According to the graphs it is proven that using plastic increased the voids filled with bitumen

4. The decrease in air voids percentage is also observed in the plastic mix thus, preventing the pavement from minor failures.

5. The Results have shown higher stability value at 5% binder content. Hence, it is considered as the optimum bitumen content for the design of bituminous concrete mix along with 8% plastic to the weight of bitumen. This design mix is used to construct a flexible pavement

6. The increasing plastic waste can be reduced efficiently by using it in construction of flexible pavements, but experimental study should be properly carried out before coming to a concrete conclusion.

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