OPTIMISATION OF WASTE PLASTIC CONTENT IN DENSE BITUMINOUS MACADAM USING VG30 BITUMEN FOR NORTH INDIAN CLIMATIC CONDITION

by

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ABSTRACT

Due to the non-biodegradability and unsightly appearance of plastic waste, it poses a significant environmental challenge globally. An effective solution is incorporating plastic waste into flexible pavement construction, a method shown to enhance environmental sustainability and improve the performance of bituminous mixes in road surfaces. Research has investigated the impact of varying plastic waste percentages on the quality and strength of flexible pavements, using the Marshall Stability test to assess strength.

An attempt has been made to check the effect of different percentage of plastic waste content on the quality and strength parameters of the flexible pavement. Marshal Stability test was used to study the strength parameters of the flexible pavement with plastic waste. Five different content was considered for the preparation of the mix, i.e. 6%, 8%, 10%, 12% and 14% of the bitumen by weight was considered. Test results show that mix with 10% plastic waste content has maximum stability as compared to other mixes.

Keywords: Bituminous Mix, Flexible pavement, Dense Bituminous Macadam and Marshall Test.

INTRODUCTION

Polymer-modified bitumen, enhanced with waste plastic, is gaining importance in flexible pavement construction due to its improved properties. By partially replacing conventional materials, waste plastic helps achieve desirable mechanical characteristics in road mixes. In traditional road construction, bitumen serves as a binder; however, modifying bitumen with waste plastic results in a flexible pavement layer with superior binding, stability, density, and water resistance. Studies, particularly those using recycled polyethene, have shown that this mix reduces rutting and minimizes cracking in low temperatures.

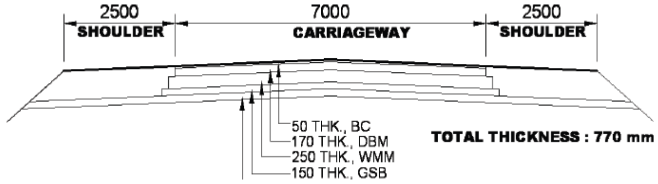

FIGURE 1 COMPONENT OF FLEXIBLE PAVEMENT AS PER IRC:37-2012

Field tests confirm that processed plastic waste, when used as an additive, not only extends pavement lifespan but also addresses environmental concerns, as plastics degrade slowly and are highly resistant to natural breakdown processes. This innovative approach offers a sustainable solution by enhancing road quality while tackling plastic waste disposal issues.

1. Flexible Pavement

Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. A flexible pavement structure is typically composed of several layers of material. Each layer receives the loads from the above layer, spreads them out and then passes these loads to the next layer below. Typical flexible pavement structure is shown in figure 1.

In flexible pavement construction, the structure typically involves multiple layers, each selected for its ability to handle varying levels of stress due to traffic loads. The highest quality materials are placed on top, where stress intensity is greatest, while lower quality materials can be used in deeper layers, where stresses are lower. Common layers, as specified in the MORTH (Ministry of Road Transport and Highways) guidelines, include:

1. Bituminous Concrete (BC): This top layer is designed for high durability and wear resistance under direct traffic loads.
2. Dense Bituminous Macadam (DBM): Primarily used as a binder course for roads with significant heavy vehicle traffic. DBM offers flexibility in gradation to optimize the mix's performance without compromising pavement durability. It also serves as a road base and is typically constructed in a single layer over the base or sub-base.
3. Bituminous Macadam (BM): Often serves as an intermediate layer in flexible pavements, providing additional support between the base and surface layers.
4. Wet Mix Macadam (WMM): A layer that provides structural strength to the pavement. It is composed of well-graded aggregates mixed with water for cohesion and stability.
5. Granular Sub-base (GSB): The lowest layer, providing a stable foundation for the upper layers.

For DBM, the Marshall Mix Design method is generally employed to ensure that the mix achieves adequate compaction, which is essential for the pavement's long-term performance.

2. Material Used

For the study, Hot mix asphalt was used for the DBM. The materials used were as following:

Bitumen: VG30 grade bitumen was used for the preparation of DBM. The samples were tested and found complying with Indian Standard Specifications for “Paving Bitumen” IS: 73, and of the penetration specified by MORTH Specifications for Road and Bridge Works (Fourth Revision) Reprint March 2007 for Dense Bituminous Macadam.

Aggregates: - The aggregates for the DBM mix consists of crushed rock and crushed sand, as available in the laboratory. The aggregates Cleanliness, Particle Shape, Strength, Water absorption and Stripping properties were tested as per IS 2386 Part I, III, IV and IS 6241weretested and found conforming with the Indian Standard. The aggregates to be used for the sample were graded as the nominal maximum aggregate of 19mm as per Table 500-7, Clause 504.3.1, of MORTH Specification for Road and Bridge works (Fifth Revision).

Plastic Waste: The plastic waste used in the testing was taken from the local waste disposal plant in Chandigarh. The plastic waste collected was the waste poly-bogs with a thickness between 40 to 60 microns. The collected waste was shredded in the shredder in the local market. The shredded plastic wastes were having an area between 50mm^2 to 70 mm^2. The image of the plastic wastes which were used for the replacement of the bitumen is as shown in Figure

2.

FIGURE 2 IMAGE OF THE PLASTIC WASTE USED.

3. Marshall Test and Specimen Preparation

The Marshall Stability and Flow Test is a crucial evaluation in the Marshall Mix design method, providing a performance prediction for bituminous pavement materials. In this test:

- Stability measures the maximum load a test specimen can withstand before failure, indicating the strength of the mix. The load is applied at a consistent rate of 50.8 mm per minute until the specimen reaches its failure point. The highest load achieved is recorded as the stability value.
- Flow measures the deformation or plastic flow of the specimen under load. As the load is applied, a dial gauge monitors the specimen's deformation, which provides insight into the material's flexibility and its ability to withstand traffic-induced stresses without cracking.

In this study three set of specimens were made with content as given in Table 500-7, Clause 504.3.1, of MORTH Specification for Road and Bridge works (fifth Revision), for 19 mm nominal maximum size aggregate as shown below in Table 1. The bitumen content was considered as 6% instead of 3.4% after studying the existing research papers for laboratory testing.

Grading	**1**	**2**
Nominal maximum aggregate size (mm)	40	19
Layer thickness	80-100	
IS Sieve size (mm)	Cumulative % by weight of total aggregate passing	
45	100	-
37.5	90-100	-
26.5	75-100	100
19	-	90-100
13.2	35-61	56-88
4.75	13-22	16-36
2.36	4-19	4-19
0.3	2-10	2-10
0.075	0-8	0-8
Bitumen content	3.3	3.4

TABLE 1AGGREGATE GRADING USED AS PER MORTH TABLE 500-7, CLAUSE 504.3.1.

As per the requirements of Marshal Stability test 1200gm of the aggregate was taken with grading as mentioned in table 1 for the preparation of each specimen for the nominal maximum aggregate size of 19mm. Total three numbers of specimens were first made with the specification as given in Table 1 but with bitumen content of 6% (Mitul Patel et al., 2014; Naveena N, 2018).

Then for the study three numbers of specimens for each replacement of a plastic mix of 6%, 8%, 10%, 12% and 14% of bitumen by weight were prepared. Table 2 shows the mixed content of the specimens made for the testing. The specimens were Designated/labelled for the ease of the study and to avoid any confusion at a later stage. The designation code M6%WP means M implies Mix, WP is waste plastic with its content of 6%

Mix Designation	Quantity of the material for a single specimen			Number of specimens made
	Aggregate (gm)	Bitumen(gm)	Plastic Mix(gm)	
M0%WP	1200	72	0	3
M6%WP	1200	67.68	4.32	3
M8%WP	1200	66.24	5.76	3
M10%WP	1200	64.80	7.20	3
M12%WP	1200	63.36	8.64	3
M14%WP	1200	61.92	10.08	3

TABLE 2 QUANTITY OF MATERIALS USED FOR EACH SPECIMEN.

4. Result and Discussions

The specimens made as stated in the above section were tested on the Marshall stability testing machine and the result of the mixes are tabularized as following:

Sample No.	**Mix Designation**	**Thickness (mm)**	**Marshall Stability**	**Correction Factor**	**Corrected Marshall Stability**	**Marshall Flow (mm)**
1	M0%WP	66.1	1950	0.941	1834.95	2.35
2		66.2	1925	0.939	1807.58	2.40
3		65.9	1970	0.945	1861.65	2.25
4	M6%WP	65.8	2440	0.947	2310.68	2.80
5		66.0	2410	0.943	2272.63	2.85
6		65.7	2480	0.949	2353.52	2.75
7	M8%WP	66.1	2650	0.941	2493.65	2.85
8		65.7	2610	0.949	2476.89	2.80
9		65.9	2690	0.945	2542.05	2.80
10	M10%WP	65.1	2800	0.960	2688.00	2.90
11		65.3	2780	0.956	2657.68	2.85
12		65.1	2840	0.960	2726.40	2.95
13	M12%WP	66.1	2670	0.941	2512.47	3.10
14		65.4	2690	0.954	2566.26	3.05
15		65.8	2710	0.947	2566.37	2.95
16	M14%WP	66.4	2630	0.936	2461.68	3.15
17		66.6	2610	0.932	2432.52	3.20
18		66.7	2670	0.930	2483.10	3.10

TABLE 3 RESULTS OF MARSHALL TEST

The mean of the results of the 3 set of each Mix designations is taken to study the effect of the waste plastic on the mix. The mean of the Marshall Stability and Marshall Flow is tabularized for the ease of study in Table 4.

Sample No.	**Mix Designation**	**Mean Corrected Marshall Stability (Kg)**	**Mean Marshall Flow (mm)**
1	M0%WP	1834.73	2.33
2	M6%WP	2312.28	2.80
3	M8%WP	2504.20	2.82
4	M10%WP	2690.69	2.90
5	M12%WP	2548.37	3.03
6	M14%WP	2459.10	3.15

TABLE 4 MEAN CORRECTED MARSHALL STABILITY AND FLOW FOR DIFFERENT MIX DESIGNATIONS.

Figure 3 shows a graph which shows the variation of Mean Corrected Marshall Stability with respect to an increase in waste plastic content.

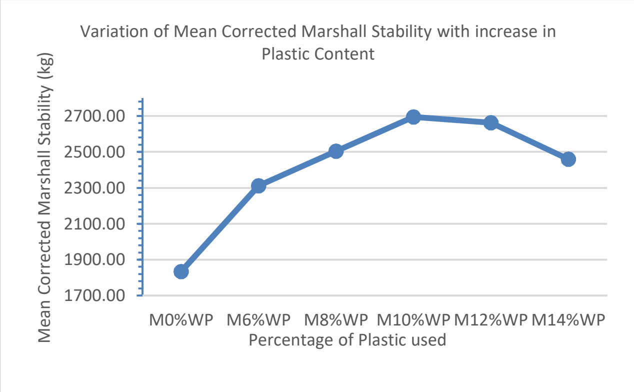

FIGURE 3VARIATION OF MEAN CORRECTED MARSHALL STABILITY WITH INCREASE OF WASTE PLASTIC CONTENT

The study of the Marshall stability shows that with the increase of the waste plastic mix the stability number increases by 855.96 kgs which are about 46% increase in its load-bearing, which can be considered as an additional benefit at a reduced cost. It was also found that if the waste plastic content is further increased, then the stability number starts reducing from the peak value at 10% waste plastic content. Also, the reduction is 231.59 kgs from the peak value which is merely 12.6% of the stability number with zero plastic content. Thus, it can be considered that a higher plastic content can also be used without compromising the stability of the mix and there will be gain in the stability due to the addition of the waste plastic.

Similarly, Study was performed on the variation of Marshall Flow with the increase of waste plastic content. Figure 4 shows the increase in Marshall Flow with respect to the waste plastic content.

While studying the values of the Marshall flow, it can be considered that Marshall flow value increases with the increase of waste plastic content. The trend of the rate of increase of Marshall Flow with an increase in waste plastic can be considered almost linear, with little exceptional local peak for the mix with waste plastic content of 6%.

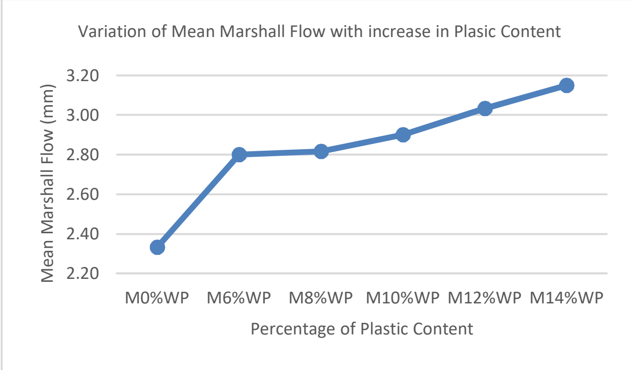

FIGURE 4 VARIATION OF MEAN MARSHALL FLOW WITH INCREASE IN WASTE PLASTIC CONTENT

In the third phase of the study, the variation of Marshall stability and Marshall flow was studied together with the increase of the waste plastic content. Figure 5 shows the variation relation of the three parameters.

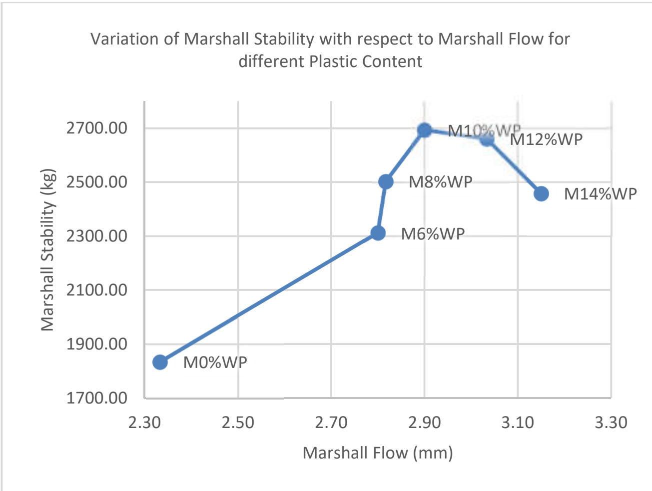

FIGURE 5 VARIATION OF MARSHALL STABILITY AND FLOW WITH INCREASE IN WASTE PLASTIC CONTENT.

When the Marshall stability was studied along with the flow, then it was observed that a global maximum exists for the curve for the mix with waste plastic content of 10%, with 0.57mm increase in the flow which is about 24.4% of the zero-waste plastic mix flow.

It is observed that in mix with waste plastic content of 10% the gain in strength is 46% as compared to the gain in flow of 24.4%, so it can be considered that 10% is the optimum content of waste plastic, where the gain in stability is almost double the loss due to increase of flow. Hence it can be considered as the optimum content to be used for the additional benefits of increased stability while keeping the flow within the limits which can be 3.4mm at maximum.

Conclusion

From the above test and its results, it can be concluded that if the plastic waste from the waste poly-bogs with thickness between 40 to 60 microns after shredding to an area in between 50mm^2 to 70 mm^2, is used in the construction of roads with dense bituminous macadam then following enhancement of the properties of the dense bituminous macadam is possible:

a) With the increase of plastic content, the Marshall stability value increases to a maximum at 10% bitumen replacement with waste plastic by weight as optimum content.

b) With the increase of the plastic content, the value of Mean Marshall Flow also increases considerably.

c) It was observed that Marshall Stability increases up to maximum till plastic content of 10% but with the further increase of plastic content, the value of Marshall Flow continues to rise while Marshall Stability falls.

From the above observation, the plastic wastes may be used in highways construction with certain advantage by considerably reducing the impact of the plastic waste on the environment and society.

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