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Experimental Analysis of Flexible Pavement Structure Using Waste Plastic

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***Abstract*: This paper mainly deals with providing a sustainable and a pro-environmental measure to construct a flexible pavement using thermoplastic modifiers, namely High density polyethylene (HDPE) into the conventional VG 40 grade bitumen sample in different percentage so as to find the proper percentage of blend so as to provide a pavement of good quality with minimal or no maintenance cost and also to reduce the cost of construction and maintain an economy by reducing the percentage of bitumen by replacing it with plastic in shredded form. It also helps in managing a way for disposal of solid waste, particularly Plastic waste and to meet the Millenium Development Goals (MDG). Using of waste plastic such as HDPE or LDPE in shredded form has proven to show promising results both for the environment as well as the pavement construction in term of providing better riding quality and increase in Marshal Stability value and reduction in flow value as compared to conventional bitumen sample.**

***Keywords*: Thermoplastic modifiers, HDPE, LDPE.**

1. Introduction

Using waste Plastic in road construction is a sustainable way to fulfill this demand and also to tackle the problem of plastic waste disposal. The inclusion of thermos plastic modifiers to virgin bitumen sample is known to improve the viscoelastic behaviour of the bitumen and also improves the overall rheological properties of the sample. This research mainly deals with providing a sustainable and a pro-environmental measure to construct a flexible pavement using thermoplastic modifiers, namely High density polyethylene (HDPE) and Low density polyethylene (LDPE) into the conventional VG 40 grade bitumen sample in different percentage so as to find the proper percentage of blend so as to provide a pavement of good quality with minimal or no maintenance cost and also to reduce the cost of construction and maintain an economy by reducing the percentage of bitumen by replacing it with plastic in shredded form. It also helps in managing a way for disposal of solid waste, particularly Plastic waste and to meet the Sustainable Development Goal (SDG). Using of waste plastic such as HDPE or LDPE in shredded form has proven to show promising results both for the environment as well as the pavement construction in term of providing better riding quality and increase in Marshal Stability value and reduction in flow value as compared to conventional bitumen sample.

2. Material and Methodology

A. General

Discussed below are the materials and various tests conducted for the project work. The material used for the project mainly comprises of bitumen of grade VG 40, aggregates varying in different sizes such as 20mm, 10mm, 6mm and dust particles and most importantly plastic in the shredded form with size passing 2.36mm IS sieve and retaining on 600 micron has been carried out.

B. Bitumen

If we define bitumen in simple terms, it is a substance that is formed by distilling crude oil and is known for its waterproofing and adhesive properties. Distillation of bitumen eliminates lighter crude oil components including gasoline and diesel, leaving only the "heavier" bitumen. Bitumen is present in different grades depending upon their type of grading. There are different methods of grading of bitumen such as chewing, penetration grading, viscosity grading and superpave performance grading of bitumen.

The grade of bitumen used for the project work in bitumen of viscosity grade VG 40. VG-30 is used in highly stressed areas such as intersections, near toll booths and truck parking lots. Due to its higher viscosity, stiffer Bitumen mixes can be produced to improve resistance to shoving and other problems associated with higher temperature and heavy traffic loads. The bitumen sample used for the project work belonged to Indian Oil ltd.

C. Aggregates

Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction. Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course. They also have to resist wear due to abrasive action of traffic.

The aggregate used for the project was from Balacherra quarry Silchar.

D. Plastic waste

From plastic containers, bottles, bags to plastic toys; everywhere we look, we see most of the plastic items made of polyethylene! It is one of the most popular thermoplastic

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materials available today. Polyethylene is a lightweight, durable thermoplastic with variable crystalline structure. It is one of the most widely produced plastics in the world (tens of millions of tons are produced worldwide each year). Polyethylene is used in applications ranging for films, tubes, plastic parts, laminates, etc. in several markets (packaging, automotive, electrical, etc.).

Polyethylene is made from the polymerization of ethylene (or ethene) monomer. Polyethylene chemical formula is (C2H4)n.

According to the provisions mentioned by GOI in the guidelines book: Guidelines in use of Plastic Waste in Road Construction (Provisional) Guideline no. RDSO/WKS/2019/1 May-2019, they suggest that addition of waste plastic in small dose about 5-10%, by weight of bitumen helps in substantially improving the Marshall stability, fatigue life and other desirable properties of bituminous mix, leading to improved longevity and pavement performance. The use of waste plastic thus contributes to construction of green roads.

The shredded plastic used for the following project was High Density Poly-ethylene (HDPE) plastic. The size of the plastic conform to the size passing 2.36mm sieve and retained on 600 micron sieve. The plastic was purchased from two different Saguna Sales Corporation (Pune).

High Density Polyethylene (HDPE) is a cost-effective thermoplastic with linear structure and no or low degree of branching. It is manufactured at low temperature (70-300°C) and pressure (10-80 bar) & derived from either:

1. Modifying natural gas (a methane, ethane, propane mix) or
2. The catalytic cracking of crude oil into gasoline

HDPE is produced majorly using two techniques: Slurry Polymerization or Gas Phase Polymerization.

$$-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-$$

Fig. 1. High density polyethylene molecular structure

High density polyethylene is flexible, translucent/waxy, weather resistant, and displays toughness at very low temperatures.

1) Properties of High Density Polyethylene

1. HDPE Melting point: 120-140°C
2. Density of HDPE: 0.93 to 0.97 g/cm3
3. High Density Polyethylene Chemical resistance
4. Continuous temperature: -50°C to +60°C, Relatively stiff material with useful temperature capabilities
5. Higher tensile strength compared to other forms of polyethylene
6. Low cost polymer with good process-ability
7. Good low temperature resistance
8. Excellent electrical insulating properties
9. Very low water absorption
10. FDA compliant

2) Disadvantages of HDPE

1. Susceptible to stress cracking
2. Lower stiffness than polypropylene
3. High mold shrinkage
4. Poor UV and low heat resistance
5. High-frequency welding and joining impossible

However, weathering resistance of HDPE can be improved by the addition of carbon black or UV absorbing additives. Carbon black also helps to reinforce the material.

Fig. 2. Shredded HDPE waste plastic passing sieve 2.36mm and retained 600 micron sieve

Fig. 3. Plastic shredding machine

a) Waste plastic shredding:

Shredding is the process of cutting the plastic into small sizes between 2.36mm to 4.75mm with the help of the plastic shredding machine viz. Agglomerator and Scrap Grinder.

b) Details of Shredding Machine:

For shredding of poly-ethylene "Agglomerator" is used. In this process, plastic wastes are cut in small pieces with the help of rotor blades. The process is completed in about half an hour.

The shredded waste plastic was sprayed over the hot aggregate which got coated on aggregate when molted. The extent of coating was varied by using different percentage of plastic. Increase in the percentage of plastic increases the properties of aggregates.

3. Methodology

There are basically two methods of mixing the polymer to the bituminous mix, namely:

1. Dry Mix Method: In this method, the polymer is poured into hot bitumen and then the resulting solution is added to the hot aggregate preferably at 165°C.
2. Wet Mix Method: In this method, the aggregate when heated up to 165-170°C is added up the preferred polymer which gives a poly coated aggregate and further to this mix hot bitumen (about 160°C) is poured which gives a Poly Bitumen

Aggregate Mixture.

For the project work after deliberate studying, Wet mix method was selected. The steps for the project work is further explained:

1. Various tests mentioned above were conducted on aggregate. Three trials each for aggregate sample was collected and an average value was taken.
2. According to the MORTH, for BC Grade I mix design was carried out and accordingly the gradation was prepared.
3. The results were collected accordingly and an average value was taken and a proper mix design for the same was made.
4. Marshall Stability and flow value for the virgin sample (without HDPE) was conducted.
5. The result showed that bitumen content of 5.5% had the maximum stability value.
6. Now for the same gradation with 5.5% bitumen content the percentage of 6mm aggregate and sand dust was reduced and same amount was been replaced by HDPE. The reduction in the percentage of aggregate and sand dust was in the ratio 75 and 25 % respectively of the plastic content.
7. Waste plastic in the form of HDPE in the size sieve passing 2.36mm and retained on sieve size 600 micron was taken and wet method of mixing was carried out.
8. The HDPE percentage was varied ranging from 2, 4, 6, 8, 10 and 12% and samples were checked for their Marshall Stability and flow value.

4. Test Conducted

A. Aggregate Impact Value Test (AIV): IS 2386-4 (1984)

This test covers the procedure for determining the aggregate impact value of the aggregate:

Uses of the test:

1. To determine the impact value of the aggregates used in pavement construction(Road);
2. To assess their suitability in road layers (base course, surface course) construction on the basis of impact value.

B. Apparatus used in Impact test

The apparatus of the aggregate impact value test consists of:

1. A testing machine weighing 45 to 60 kg and having a metal base with a plane lower surface of not less than 30 cm in diameter. Level and plane concrete floor of minimum 45 cm thickness are used to support it. The base of the machine should also have provisions for fixing its base.
2. A cylindrical steel cup of internal diameter 102 mm, depth 50 mm and minimum thickness 6.3 mm.
3. A metal hammer or tup weighting 13.5 to 14.0 kg the lower end is cylindrical in shape, is 50 mm long, 100.0 mm in diameter, with a 2 mm chamfer at the lower edge and case hardened. The hammer is arranged in such a way that it should slide freely between vertical guides and be concentric with the cup. It is arranged that the free fall of the hammer should be within 380±5 mm.
4. A cylindrical metal measure having an internal diameter of 75 mm and depth 50 mm for measuring aggregates.
5. One end rounded tamping rod 10 mm in diameter and 230 mm long.
6. A balance of capacity not less than 500 g, and readable and accurate up to 0.1 g.

Fig. 4. Aggregate impact value test being conducted

C. Specific Gravity Test: IS 2386-3 (1963)

Specific Gravity is defined as the ratio of Weight of Aggregate to the Weight of equal Volume of water. The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregates having low specific gravity are generally weaker than those with high specific gravity. This property helps in a general identification of aggregates.

Procedure of water absorption and specific gravity test on aggregates:

There are three methods of testing for the determination of the specific gravity of aggregates, according to the size of the aggregates larger than 10 mm, 40 mm and smaller than 10 mm. For Samples larger than 10 mm, 40 mm, the below given test method is used and for samples smaller than 10 mm Pycnometer test is done.

Fig. 5. Apparatus for testing specific gravity and water absorption of aggregates

1) Apparatus Required

1. A balance of capacity about 3kg, to weigh accurate 0.5g, and of such a type and shape as to permit weighing of the sample container when suspended in water.
2. A thermostatically controlled oven to maintain temperature at 100-110° C.
3. A wire basket of not more than 6.3 mm mesh or a perforated container of convenient size with thin wire hangers for suspending it from the balance.
4. A container for filling water and suspending the basket.
5. An air tight container of capacity similar to that of the basket.
6. A shallow tray and two absorbent clothes, each not less than 75x45cm.

D. Particle size Distribution Test: IS 2386-1 (1963)

For determination of particle size distribution of fine, coarse and all-in-aggregates by sieving.

5. Equipment and Apparatus

- Balance (0-10kg)
- Sieves
- Oven

A. Test sample preparation

The sample is prepared from the larger sample either by quartering or by means of sample divider. Minimum sampling weights is as per table given below.

Fig. 6. Sieves used for particle size distribution

B. Penetration Test: IS: 1203-1978

The penetration test of bitumen measures the hardness or softness of bitumen by measuring the depth of penetration of standard loaded needle in five seconds while maintaining bitumen sample temperature at 25 °C. The more viscous the bitumen, the less distance needle is able to penetrate. Hence, the penetration value for viscous bitumen is less.

Apparatus:

Following apparatus required for a penetration test.

Penetrometer: It is the testing machine for bitumen penetration tests. It allows fixation of penetration needle, plunger, weight, and a dial. It allows the needle to penetrate into the sample placed in the cup without considerable friction. It should be accurately calibrated so that it gives the results in one-tenth of a millimeter.

Fig. 7. Penetration test of bitumen

C. Softening Point Test: IS code 1205

The softening point shows the temperature at which the bitumen gains a certain degree of softening under the specifications of the test. This test is carried out by using the Ring and Ball apparatus. The softening point helps to determine the temperature up to which bitumen can be heated for different road use applications.

Apparatus: Apparatus used in ring and ball test of bitumen

Fig. 8. Ring & Ball apparatus

D. Marshal Stability and Flow value

The mix design (wetmix) determines the optimum bitumen content. This is preceded by the dry mix design discussed in the previous chapter. There are many methods available for mix design which vary in the size of the test specimen, compaction, and other test specifications.

Specimen preparation:

Approximately 1200gm of aggregates and filler is heated to a temperature of 175-190°C. Bitumen is heated to a temperature of 121-125°C with the first trial percentage of bitumen (say 3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 154-160°C. The mix is placed in a preheated mould and compacted by a rammer with 50 blows on either side at temperature of 138°C to 149°C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Vary the bitumen content in the next trial by +0.5% and repeat the above procedure. Number of trials are predetermined. The prepared mould is loaded in the Marshall test setup.

Fig. 9. Marshall sampling mould

Table 1
Aggregate impact value results

S.No.	Description	Sample 1	Sample 2
1	Weight of Dried Sample	340	360
2	Weight of Crushed Particle passed through 2.36mm sieve	50	65
3	Impact value	15	18
4	Average Value	16.5	

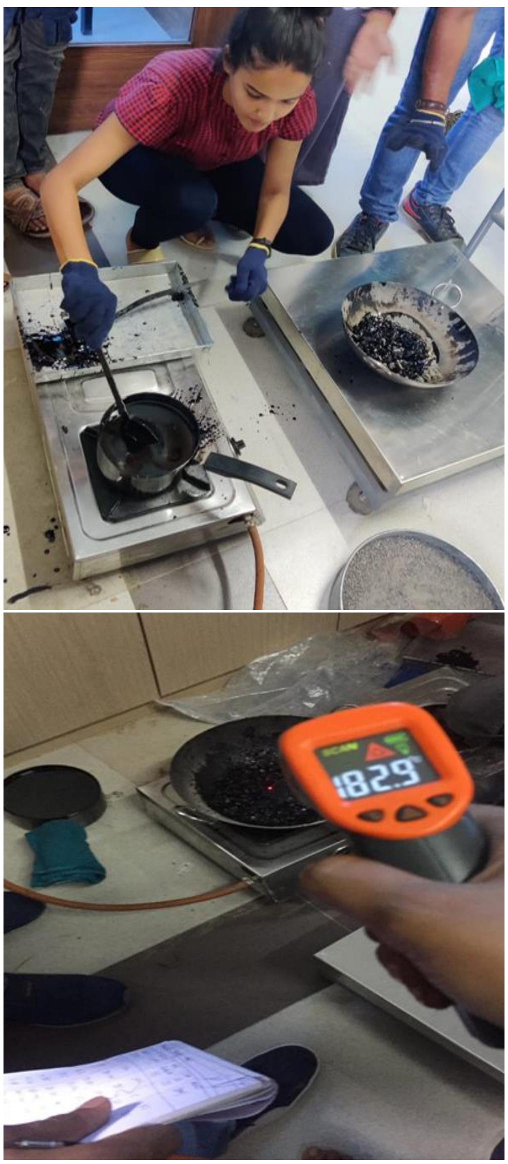

Fig. 10. Practicing Marshal mix design

6. Results and Discussion

A. General

Following test were conducted for the project work to identify the plastic performance with the bituminous mix. The tests were conducted on virgin aggregate and bitumen sample and the test results were recorded to check with the required standard given in IRC. All the results of the samples collected and tested were in compliable with the standard norms prescribed by IRC and given in IS codes or ASTM codes.

Aggregate Impact Value Test (IS 2386 Part 4):

This test gives the measure of resistance to impact or applied shockthat could differ from the resistance to gradually applied compressive load. The test was conducted on samples of aggregate sized 10.0 mm to 12.5mm size. Aggregates are dried by heating them at around 100-110° for about 4 hours and then cooled.

From the results it can be said that the sample used complies with the recommended value and the average aggregate value being 16.5 the sample falls in the category of “Strong”.

Specific Gravity (IS 2386 Part 3):

The pycnometer is used for determination of specific gravity of soil particles both fine and coarse.

Table 2
Specific gravity test on aggregate results

S.no.	Description	Observed Value
1	Weight of Pycnometer	1034
2	Weight of Aggregate+ Pycnometer	2345
3	Weight of Aggregate, Water & Pycnometer	2654
4	Weight of Water & Pycnometer	1847
5	Apparent Specific gravity	2.60

The specific gravity of aggregate normally used in construction process usually ranges from about 2.5 to 3.0 with the average value ranging about 2.68. From the test conducted the result of apparent specific gravity is 2.60 which complies with the recommended values.

Particle Size Distribution (IS 2386 Part 1):

This test is used to determine the distribution of aggregate particles by size within a given sample. The results for this test is used for the design and production requirement.

Table 3
Particle size distribution result

IS Sieve in mm	20mm	10mm	6mm	SD	Design Grading
	10%	28%	30%	32%	100%
19	10	28	30	32	100
13.2	5.75	28	30	32	95.75
9.5	2.5	19	30	32	83.5
4.75	0	3	30	32	65
2.36	0	1	21	29	51
1.18	0	0	12.5	27	39.5
0.6	0	0	5.5	23	28.5
0.3	0	0	4.5	16	20.5
0.15	0	0	2.1	12	14.1
0.075	0	0	1.5	4	5.5

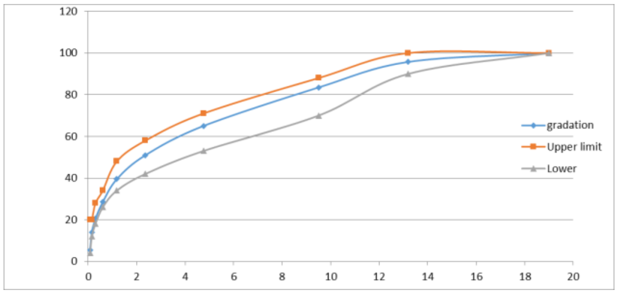

Fig. 11. Particle size distribution

The grading has been done for BC layer for Grade 1 and accordingly the percentages of aggregates have been fixed. From the gradation chart and graph the values of the aggregate have been adjusted into the prescribed upper and lower limits.

Penetration Value (IS 1203-1978):

This test measures the hardness or softness of bitumen sample by measuring the depth of loaded standard penetration needle for 5 seconds of penetration at a room temperature of 25°C.

From the acquired result it can be said that the bitumen sample for VG 40 complies with the standard permissible limits given according to the IS code.

Softening Point Test (IS 1205):

The softening point is defined as the mean of the temperatures at which the bitumen disks soften and sag downwards a distance of 25 mm under the weight of a steel ball.

From the results obtained it can be seen that the value of the test falls within the permissible limits criteria.

Marshall Mix Design:

Marshal test is conducted on the conventional as well as the plastic coated sample to get flow and stability value to determine optimum binder content. Following results are obtained for this trial:

Specific gravity of bitumen (Gb): 1.057

Eff. Sp. Gravity of aggregate (Gse): 2.6

Proving ring factor: 0.282x + 0.1763

Bulk Sp. Gravity of aggregate (Gsb): 2.6

Table 7
Marshall stability and flow value for sample without plastic

S.no.	% bitumen	stability	flow
1	4.5	10.35	2.7
2	5	10.58	2.9
3	5.5	10.8	3.1
4	6	10.64	3.9

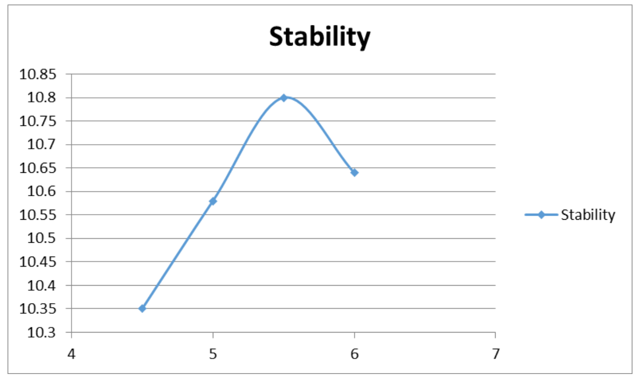

Fig. 12. Stability value for sample without plastic

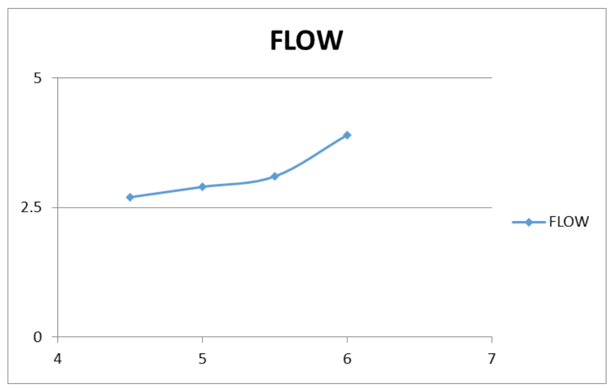

Fig. 13. Flow value for sample without plastic

Table 4
Penetration value result

S. No.	Description	Test 1	Test 2	Permissible limit	Specifications
1	Initial Reading	10	12		IS-1203:1978
2	Final Reading	76	76		
3	Penetration Value	86	88		
	Average Value	87		80 - 90	

Table 5
Softening point test results

S. No.	Description	Ball 1	Ball 2	Permissible Limits in IS 1205
1	The Temperature when Ball touches the bottom	49	48	45 - 55
2	Average Value	48.5		

Table 6
Marshall Stability and flow value for sample without plastic

S.no.	% of bitumen	Ht. of specimen (mm)	Wt of specimen in air	Wt of specimen in water	Bulk Volume	Bulk Comp. Mix	Max. Specific gravity (Gmm)	Va	VMA	VFB	Stability		Flow
											Measured	Corrected	
1	4.5	67	1177.33	655	2.6	2.273	2.41	5.94	17.71	66.46	361	10.35	2.7
2	5	65	1147	642.33	2.6	2.643	2.41	5.56	17.38	68.01	369	10.58	2.9
3	5.5	70	1284	724.33	2.6	2.294	2.41	4.82	15.29	68.48	377	10.8	3.1

Table 8
Marshall design with plastic

Sr.no.	% plastic with 5.5 % bitumen	stability	flow
1	0	10.8	2.6
2	2	11.9	2.7
3	4	12	2.8
4	6	12.9	2.96
5	8	13.3	3.4
6	10	12.8	3.8
7	12	11.8	4.1

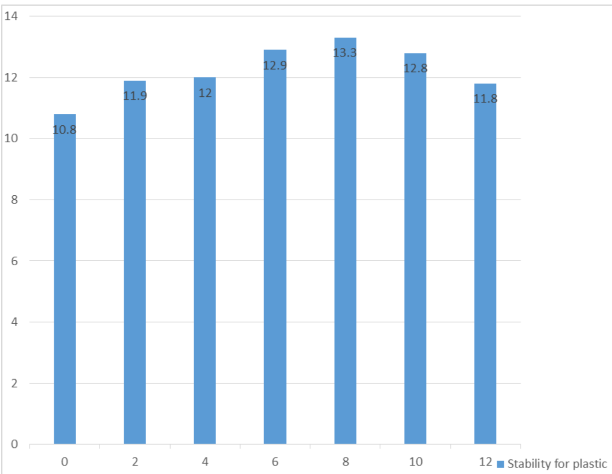

Fig. 14. Stability value for sample with plastic

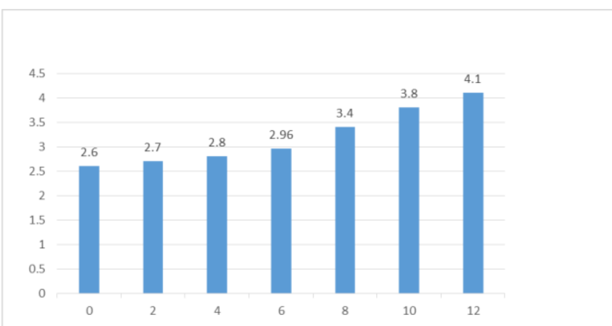

Fig. 15. Flow value for sample with plastic

Design of Flexible Pavement (IRC 37-2018):

Considering the CBR values mentioned in table a dual lane flexible pavement (7m width) was designed as per IRC 37 2018 for CBR value 8%.

Design of flexible pavement for two lane single carriageway national highway (CBR 8%)

Classification of road: National Highway

Terrain: Plain

Proposed Carriageway: Intermediate Carriage way

Design Life: 15 years

Min. Traffic growth: 7.5%

Initial traffic in the year of completion of construction = 400 CVPD (sum of both directions)

Axle Load Survey and VDF Calculation

Vehicle Damage Factor: 1.5

Lane Distribution Factor: 0.75

Design CBR of Subgrade: 8%

Design traffic Calculation: $N = [365 \times \{(1+r)^x-1\} \times A \times D \times F]/r$

$= [365 \times \{(1+0.075)^{15}-1\} \times 400 \times 0.75 \times 1.5]/ 0.075$

$= 5$ MSA

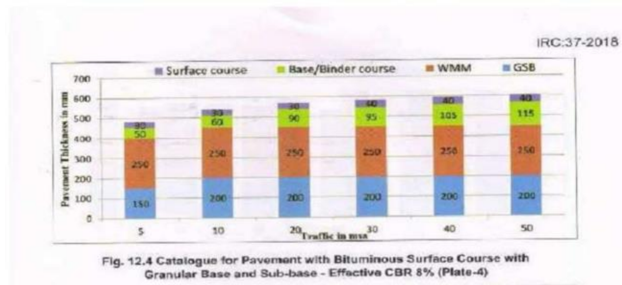

Fig. 16. Total Pavement thickness as per IRC 37:2018 fig. 12.4

Design result:

1) Bituminous layer – 30mmv (BC) + 50mm (DBM)
2) WMM - 250mm
3) GSB – 150mm

Total thickness – 480mm

Bitumen used is VG40

7. Conclusion

The study investigated the use of High Density Poly ethylene (HDPE) plastic in the use of road construction. All the tests were successfully conducted and the result showed that the use of HDPE plastic in road construction for BC Grade I can be carried out successfully and also with any hazard if proper precautions and safety is maintained. Use of HDPE plastic results in better durability and sustainability of construction as it decreases the penetration value, increases the softening value, reduces the aggregate impact value and crushing value. Hereby, indicating that use of polymer in construction can lead to increase in toughness of bitumen and also increases the aggregate bonding with the binder. Because of which the need of anti-stripping agent can also be neglected and thus economy can be achieved.

From the tests performed and results collected we can conclude that:

Advantages:

1. Aggregate of 6mm and Sand dust was replaced by HDPE plastic in proportion of 75% & 25% respective to plastic percentage and it was found that with plastic content of 8% higher stability value was achieved. Thus economy was achieved by reducing the aggregate content.
2. From the test performed it was possible to save of the percentage of aggregate, and achieve economy.
3. Use of plastic coated aggregate has shown better performance in the stability and flow values for Marshall Mix Design.
4. The plastic mixed with bitumen and aggregates is used for the better performance of the roads. The polymer coated on aggregates reduces the voids and moisture absorption. This results in the reduction of ruts and there is no potholes formation. The plastic

pavement can withstand heavy traffic and are durable than flexible pavement. The use of plastic mix will reduce the bitumen content by 8-10% and increases the strength and performance of the road.
5. This technology is eco-friendly, also called as green roads.
6. Use of plastic waste in road construction is a durable and sustainable option for the betterment of generations to come.
7. It also saves on a lot of economy because of bitumen reduction.
8. Plastic will increase the melting point of the bitumen. Use of innovative technology not only strengthens the road construction but also increases the road life.
9. If plastics are used in such smart ways, it will be a boon to India's hot and humid climate where sustainable and eco-friendly roads will contribute towards curbing of plastic waste.
10. Also plastic coated aggregate shows better compressive strength and bending strength.
11. Moreover this technique would also generate employment for rag-pickers.

Disadvantages:
1. The blending of binder and polycoated aggregate should be carried out in the supervision of an expert.
2. Any kind of mishandling or mishap can cause casualty or pollution.
3. Burning of plastic will release some amount of pollution.

Future scope:
1. Use of plastic in construction is a newly advanced technology and surely has a wide scope of expansion and innovation.
2. Plastic considered to be a waste or single use plastic can be used for innovative methods and proper disposal of such waste can be expected in the form of construction process.
3. The use of plastic with some stabilizers is totally a strong future scope for expansion in the use of the technique for high traffic volume roads.
4. A proper design procedure can be made by for the use of plastic in road construction for flexible pavement. Mixing of plastic with bitumen mix can be achieved in a controlled and safe environment.

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