Laboratory Investigation of Bituminous Mix Properties using Waste Polyethylene Terephthalate

Vibhuti Patel[1], Vishwa Patel[2], Pooja Prajapati[3], Ankit Rathod[4], Dixit H. Chauhan[5]

[1,2,3,4]UG Student, Department of Civil Engineering, Bhagwan Mahavir College, Gujarat, India
[5]Assistant Professor, Department of Civil Engineering, Bhagwan Mahavir College, Gujarat, India

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Abstract - *Nowadays, flexible pavements with bituminous surface are widely used. Due to increase traffic intensity of roads, overloading of commercial vehicles and temperature variation of pavements due to climatic changes leads to formation of various distresses like rutting, bleeding, cracking and potholing of bituminous surfacing. Due to high temperature, bitumen become very soft in summer and brittle in winter. Also in a developing country like India, roadway construction is taking place at a very high speed which require large demand of construction material that too eco-friendly and economical. Several studies have revealed that properties of bitumen and bituminous mixes can be improved with addition of certain additives and the bitumen premixed with these additives is known as "modified bitumen". The present study aims for use of modified bitumen by using waste polyethylene terephthalate for road construction. Using waste polyethylene terephthalate as a secondary material in construction projects would be a solution to overcome the crisis of producing large amount of waste plastics in one hand and improving the structure's characteristic such as resistance against cracking on the other hand. The modified bitumen mix shows better binding property, density and more resistant to water.*

***Key Words*: Modified bitumen, Waste polyethylene terephthalate, Mixture properties**

1. INTRODUCTION

As a result of rapid industrial growth in various fields together with population growth, an obvious increase in waste generation rates for various types of waste materials is observed. Disposal of that large amount of wastes especially non-decaying waste materials become a problem of great concern in developed as well as in developing countries. Recycling waste into useful products is considered to be one of the most sustainable solutions for this problem. So that, research into new and innovative uses of waste materials is extensively encouraged.

Safe disposal of waste plastic is a serious environmental problem. Being a non-biodegradable material it does not decay over time and even if dumped in landfills, finds its way back in the environment through air and water erosion, can choke the drains and drainage channels, can be eaten by unsuspecting grazing animals causing them illness and death, can contaminate the construction fill, etc. The best way of disposal of waste plastic is its recycling to the maximum extent and many developed countries have recycled waste plastic to manufacture various products, including some used in heavy construction.

Usage of plastic products has become an integral part of every one's daily life. Industrial growth in addition to population growth resulted increased production of various types of plastic materials. The consumption of plastic materials has been growing beyond all expectation leading to several environmental problems, mainly-because of the chemical.

Reuse of waste materials in asphalt industry has emerged as a propitious way to enhance sustainability from perspectives of environment and economy. Considering the fact that plastic wastes, being non-biodegradable, persist in the environment over long time periods, their use in highway construction will help to reduce the negative impact caused due to indiscriminate dumping.

Polyethylene terephthalate (PET), a semi-crystalline thermoplastic polymer, is extensively used to produce packaging contenders for soft-drinks, food items and other consumer products. PET bottles have taken over glass bottles as preferred storage option due to ease in handling, lightweight and chemical resistance. Global consumption of PET bottles is nearly 20 million tonnes which is increasing by 15% every year (Yao et al., 2016); however, the recycling rate of PET bottles is just 29.3%, which is very low (Miller, 2012; Mariaenrica, 2010).

Use of PET in civil engineering applications such as in structural concrete and pavement construction is considered a rewarding alternative to overcome PET waste crisis.

2. Previous investigation:-

In the present study the aggregate gradation Grading-2 adopted for Bituminous Concrete as per Table 500-18 recommended by MORT&H (IVth Revision) specifications.Basic Engineering tests on aggregates and binder were conducted in the laboratory to assess their properties.

Marshall Method of mix design was adopted to carryout mix design for Bituminous Concrete Mix prepared using Polymer Modified Bitumen. Marshall Stability and Indirect Tensile Strength tests were conducted on Bituminous Concrete Mix prepared using Polymer Modified Bitumen by varying mixing and compaction temperatures. For the selected mixing and compaction temperatures Indirect Tensile Fatigue test was conducted at 25oC by varying stress level.

3. Materials and methods:-

Aggregates offer good compressive and shear strength; along with this they provide good interlocking facility with sufficient permeability. Aggregate mainly consisting of both coarse and fine aggregates. Coarse aggregate of 19 mm to 2.36 mm and fine aggregates of 2.36 mm to 75 μ were used.

The test results are presented in table 1.

Table 1: Physical Properties of Aggregates

Sr.No.	Types of test	Test method	Result	MORTH,2013 specifications
1	Aggregate impact	IS-2386 Part IV	10.56%	<27%
2	Los angeles abrasion	IS-2386 Part I	27.00%	<35%
3	Aggregate crushing	IS-2386 Part I	23.09%	<30%
4	Water absorption	IS-2386 Part III	0.7%	<2%
5	Specific gravity (Coarse aggregate) (Fine aggregate)	IS-2386 Part III	2.67% 2.50%	2-3%

Bitumen is a binding agent. At normal temperature they are in the form of semi-solid, it is heated until liquefied before blending it with the aggregates. In this study Polymer Modified Bitumen PMB-70(SBS) is used as binder. All the basic fundamental test and also the thin film oven test were carried out at specified temperature (153°C) on the bitumen sample as per the requirement. The test results were satisfying the requirements as per IRC-SP 53 2002. The results are presented in table 2.

Table 2: Physical properties of bitumen :-

Sr.No.	Types of test	Test method	Result	BIS-73:2006 Specifications
1	Penetrtion test,mm (25°C,100g,5sec)	IS:1203-1978	67.8	60-70
2	Softening point test(°C)	IS:1205-1978	48.3	40-55
3	Ductility test,cm (25°C)	IS:1208-1979	76.5	>75
4	Specific gravity test (27°C)	IS:1202-1978	1.11	>0.99
5	Viscosity(135°C)	IS:73-2013	178	>150

According to standard Marshal design method designated as ASTM D 1559-89, 15 numbers of samples each of 1200 gm in weight were prepared using five different bitumen contents (from 4 - 6% with 0.5 % incremental). Also number of samples are prepared for different proportion of waste PET (2.5, 5, and 7.5) and for different sizes of waste PET as shown in below table

SIZE OF PET	SIEVE SIZE
Size 1	2.36mm-1.18mm
Size 2	3.25mm-2.36mm

3.1 Procedure for Mix Design

- Select aggregate grading.
- Determine the proportion of each aggregate size required to produce the design grading.
- Determine the specific gravity of the aggregate, mineral filler and bitumen.
- Prepare the trial specimens with varying bitumen contents.
- Determine the specific gravity of each compacted specimen.
- Perform stability tests on the specimens.
- Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.
- Select the optimum binder content from the data obtained.
- Evaluate the design with the design requirements.

4. Marshall Method of Mix Design

4.1 Bituminous mix design

The mix design determines the optimum bitumen content. Suitably designed bituminous mix will withstand heavy traffic loads under adverse climatic conditions and also fulfil the requirement of structural and pavement surface characteristics. The objective of the design of bituminous mix is to determine an economical blend through several trial mixes. The gradation of aggregate and the corresponding binder content should be such that the resultant mix should satisfy the following conditions:

•Sufficient binder to ensure a durable pavement by providing a water proofing coating on the aggregate particles and binding them together under suitable compaction.

•Sufficient stability for providing resistance to deformation under sustained or repeated loads. This resistance in the mixture is obtained from aggregate interlocking and cohesion which generally develops due to binder in the mix.

•Sufficient flexibility to withstand deflection and bending without cracking. To obtain desired flexibility, it is necessary to have proper amount and grade of bitumen.

•Sufficient voids in the total compacted mix to provide space for additional compaction under traffic loading.

•Sufficient workability for an efficient construction operation in laying the paving mixture.

4.2 Sample preparation

Total of 1200gm of aggregates and filler put together is heated to a temperature of 160 to 170°C. Bitumen is heated to a temperature of 121 to 145 °C with the trial percentage of bitumen (say 4% by weight of the mineral aggregates). Then the heated aggregates and bitumen are thoroughly mixed at a temperature of 154 - 170°C. The mix is placed in a preheated mould and compacted by a hammer having a weight of 4.5 kg and a free fall of 45.7 cm giving 75 blows on either side at a temperature of 130 to 145°C to prepare the laboratory specimens of compacted thickness 63.5±3 mm. In this study three samples were prepared for each percentage of bitumen ranging from 4.00% to 6.00% with interval of 0.5% to obtain better result.

Figure 1: Marshall specimens for different bitumen percentage

4.3 Determination of marshall stability and flow

The load is applied at the constant deformation rate of 51 mm per minute and load and deformation readings are closely observed. The maximum load reading and thecorresponding deformation of the specimen at failure load are noted. The maximum load value expressed in kg is recorded as the "Marshall Stability" value of the specimen. The vertical deformation of the test specimen corresponding to the maximum load, expressed in mm units is recorded as the "Flow value". The specimen is removed from the test head and the test is repeated on other specimen. In mm units is recorded as the "Flow value". The specimen is removed from the test head and the test is repeated on other specimen.

Figure 2: Testing of mould in marshall test equipment

Stability flow and volumetric analysis results of BC samples for non-modified and modified mixes:

	Composition	Marshall stability 60°C	Marshall flow 60°C	Bulk density	Air voids	Voids in mineral aggregates
Units	100%B	Kg	mm	g/cc	%	%
Test methods		ASTM:D 1559	ASTM:D 1559	ASTM:D 2726	ASTM:D 3203	ASTM:D 1559
4		850	2.25	2.44	5.91	14.46
4.5		920	2.47	2.49	3.34	13.11
5		1050	2.88	2.49	2.64	13.46
5.5		985	2.97	2.49	2.35	14.15
6		880	3.48	2.48	2.13	14.90

	Composition	Marshall stability(60°C)	Marshall flow(60°C)	Bulk density	Air voids	Voids in mineral aggregates
Units		Kg	mm	g/cc	%	%
Test methods		ASTM:D 1559	ASTM:D 1559	ASTM:D 2726	ASTM:D 3203	ASTM:D 1559
Size 1	97.5%B+2.5%P					
4		1203.33	2.5	2.4244	6.581	15.31
4.5		1336.67	2.71	2.431	5.724	15.51
5		1475	2.93	2.405	6.092	16.8
5.5		1661.67	3.42	2.404	5.495	17.21
6		1078.33	4.06	2.41	4.409	17
Size 1	95%B+5%P					
4		1206.7	2.05	2.42	6.698	16.5
4.5		1356.67	2.4077	2.4	6.95	16.26
5		1496.67	2.59	2.4	6.26	15.9
5.5		1691.67	2.85	2.475	3.81	16.05
6		1155	3.44	2.46	2.792	16.25
Size 1	92.5%B+7.5%P					
4		1221.67	2.27	2.4	7.0	16.23
4.5		1393.3	2.44	2.41	6.2	16.47
5		1572.67	2.68	2.41	4.9	16.37
5.5		1765	2.93	2.43	4.2	16.74
6		1163.33	3.54	2.45	2.62	16.34

	Composition	Marshall stability(60°C)	Marshall flow(60°C)	Bulk density	Air voids	Voids in mineral aggregates
Units		Kg	mm	g/cc	%	%
Test methods		ASTM:D 1559	ASTM:D 1559	ASTM:D 2726	ASTM:D 3203	ASTM:D 1559
Size 2	97.5%B+2.5%P					
4		1329.33	2.387	2.41	6.98	15.67
4.5		1443.33	2.513	2.42	6.01	15.77

5		1606.67	2.75	2.44	4.75	15.61
5.5		1778.33	2.963	2.442	4.03	15.92
6		1155	3.77	2.44	3.5	16.43
Size 2	95%B+5%P					
4		1303.3	2.6067	2.42	6.22	15.22
4.5		1486.7	2.79	2.432	5.46	15.54
5		1713.3	2.9967	2.473	3.22	14.56
5.5		1856.7	3.4033	2.485	2.09	14.55
6		1176.7	3.8233	2.46	1.6	15.12
Size 2	92.5%B+7.5%P					
4		1315	2.69	2.41	6.82	15.99
4.5		1540	2.9433	2.143	6.03	16.3
5		1729	3.2533	2.428	4.76	15.3
5.5		1890	3.52	2.5	3.42	16.03
6		1235	4.04	2.47	1.78	15.61

5. Conclusion

Polyethylene terephthalate (PET) is the polymer used in the manufacture of plastic bottles. Plastic is non-biodegradable material which will remain in the environment for hundreds of years leading to waste disposal crisis as well as environmental concerns. Therefore, this study is focuses on the use of waste PET in bituminous mix. PET waste used is in the form of chips or granules. The IRC: SP: 98 – 2013 guideline for bituminous mix using waste plastic has been considered for reference criteria. The study was performed with three content of waste PET (2.5%, 5.0%, and 7.5% by weight of binder) and four different sizes varying from 2.36mm – 3.25mm for modified mix by dry process.
From the observations, results and analyses, the following conclusions are deduced:

References

Pavement with polymer modification exhibits greater resistance to rutting and thermal cracking, and decreased fatigue damage, stripping and temperature susceptibility (Robinson, 2004, Vasudevan et al, 2006) suggested use of waste plastic for construction of flexible pavements.

Justo(2002) States that addition of 8.0 % by weight of processed plastic for the preparation of modified bitumen results in a saving of 0.4 % bitumen by weight of the mix or about 9.6 kg bitumen per cubic meter (m 3) of BC mix. Modified Bitumen improves the stability or strength, life and other desirable properties of bituminous concrete mix.

According to V.S. Punith, (2001), some encouraging results were reported in this study that there is possibility to improve the performance of bituminous mixes of road pavements. Waste plastics (polythene carry bags, etc.) on heating soften at around 130°C. Thermo gravimetric analysis has shown that there is no gas evolution in the temperature range of 130-180°C. Softened plastics have a binding property.

Verma S.S. (2008) Concluded that Plastics will increase the melting point of the bitumen. This technology not only strengthened the road construction but also increased the road life.

Sangita et al. (2011) suggested a novel approach to improve road quality by utilizing plastic waste in road construction. According to them India spends Rs 35,000 crores a year on road construction and repairs, including Rs 100,000 crores a year just on maintenance and roads by bitumen modification lasts 2-3 times longer, which will save us Rs. 33,000 crores a year in repairs, plus reduced vehicle wear and tear.

Kalantaret al (2010) investigated the possibility of using waste PET as polymer additives for binder in asphalt mix. Waste PET is powdered and mixed in proportions 2, 4, 6 , 8 and 10 % (by the weight of OBC) with bitumen at temperature 150 C. PET modified binder resulted in higher resistance to permanent deformation and higher resistance to rutting due to their higher softening point when compared to conventional binders. Decrease in consistency and increase in the resistance to flow and temperature changes also appears in PET modified binder.

Roakade (2012) observed that the use of LDPE enhanced the Marshal Stability value of semi dense bituminous concrete (SDBC) mix by 25 % in comparison to normal mix.

Bindu and Beena (2010) studied how Waste plastic acts as a stabilizing additive in Stone Mastic Asphalt when the mixtures were subjected to performance tests including Marshall Stability, tensile strength, compressive strength tests and Tri-axial tests.