A LABORATORY STUDY ON USE OF WASTE POLYETHYLENE IN A BITUMINOUS CONCRETE MIX

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Bituminous Concrete (BC) is mostly used in surface courses of important flexible pavement construction projects such as highways, expressways, airports, parking lots etc. in India. Now-a-days, the steady increment in high traffic intensity in terms of commercial vehicles, and the significant variations in daily and seasonal temperature put engineers in a demanding situation to think of some alternatives for the improvisation of the pavement characteristics and quality by applying necessary modification processes which shall satisfy the strength, economy and environmental aspects. In India, there is an excessive use of polyethylene in day to day packaging activities. These materials after their use become a waste, which are not biodegradable. The need of the hour is to use the waste polyethylene for some beneficial purposes. This paper presents a laboratory investigation on behavior of bituminous concrete mixes made with waste polyethylene obtained from polyethylene based packets used packaging of powdered milk of a reputed brand used widely throughout Odisha province of India. Various percentages of waste polyethylene are used in a specified procedure for preparation of mixes with a selected aggregate grading as given in the Indian specifications. It is observed that the waste polyethylene helps in considerable improvements in the engineering properties of the bituminous concrete mixes, thus makes the waste material used as viable.

Key Words: Waste polyethylene, bituminous concrete, Marshall stability, flow value, air voids, indirect tensile strength.

1 Introduction

Bituminous Concrete (BC) is mostly used in surface courses of important flexible pavement construction projects such as highways, expressways, airports, parking lots etc. all over the world. It consists of bitumen (used as a binder) and mineral aggregates consisting of coarse aggregates, fine aggregates and filler in a dense form of grading which are mixed together in hot condition, laid down in layers of appropriate thicknesses and then rolled as per given procedures to get the desired well compacted pavement layers. Of late, India is passing through a time of excellent growth of economic, social and industrial development, which has led to rapid growth of infrastructure projects in the country. There has been a steady increment in high traffic intensity in terms of commercial vehicles, both in number as well as the load. The existing bitumen is not now capable enough to withstand this large number and heavy load of traffic for a considerable time. Further, the significant variations in daily and seasonal temperature put engineers in a demanding situation in that the existing bitumen is so susceptible to temperature that a particular bitumen is not able to be adaptable to a particular location where temperature variations are quite large, thus giving engineers and scientists a challenge to explore alternatives for the improvisation of the pavement characteristics and quality by use of additives to bitumen or bituminous mixes. One important development in this direction has been use of certain polymers in applying and achieving necessary modification which easily satisfies the strength, economy and environmental aspects.

In India, there is an excessive use of polyethylene in day to day packaging activities. These materials

after their use become a waste, as at once, used plastic materials are quickly thrown out. As these are not biodegradable, they are either land filled or incinerated as a measure of solid waste management. Land filling causes several geotechnical, environmental and agricultural problems, while incineration results in atmospheric pollution and hence both are not eco-friendly processes. The need of the hour is to use the waste polyethylene for some beneficial purposes. Rokade (2012) reported that the consumption of plastics in India have increased from 4000 tons/annum (1990) to 4 million tons/annum (2001) and it is expected to rise 8 million tons/annum during the year 2009. He also observed that nearly 50 to 60% of the total plastics are consumed for packaging. Gawande et al. (2012) reported that the total plastic consumption in India has gone up to 13.5 million tonnes, out of which polyethylene (PE) contributed 7.12 million tonnes in 2011. They also reported that while the per capita consumption of plastic in India is 12-16 Kg, the per capita plastic in solid waste is about 9%. This depicts a serious picture of the environment with regard to the management of plastic wastes.

This paper presents a laboratory investigation on behavior of BC mix made with waste polyethylene taken from typical packets commonly used in supply of powdered milk of a reputed brand available widely throughout Odisha state of India. For ensuring availability of large quantity of this particular waste and for expecting uniform material properties, this particular polyethylene based waste was only considered. Various percentages of this waste polyethylene are used in a specified procedure for preparation of mixes with a selected aggregate grading as given in the specifications of Ministry of Road Transport and Highways, Govt. of India (MORTH) (2006) specifications. The benefits of polyethylene used in the mix are studied with respect to various engineering properties by preparing samples of BC mixtures with and without polyethylene.

2 Review of Literature

Uddin (2004) observed that performance of the modified asphalt binders was better than the virgin asphalt in respect of several material properties, which was confirmed by more rutting measured on the control asphalt section after four years of traffic compared to Rouse Rubber, Sealoflex, and other modified binder sections.

Casey et al. (2008) examined seven widely available thermoplastic polymers out of wastes for their suitability in PMBs, namely low density polyethylene (LDPE), medium density polyethylene (MDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), polyethylene terephthalate (PET) and acrylonitrile butadiene styrene (ABS). Initial screening resulted in the elimination of MDPE, PVC, PET, ABS and PP. LDPE and HDPE were considered to offer the most promising blend and a blend based on 4% HDPE was optimised for use in SMA. Performance tests such as wheel-tracking and fatigue resulted enhanced properties compared with unmodified binders and binders incorporating cellulose fibres, though not at the same high levels with the proprietary commercially available modified binder.

Bindu et al. (2010) used waste plastic bottles, bags, wrappers, etc collected from the nearby houses and apartments and from the Cochin University campus, Kerala (India), segregated, cleaned and shredded using the shredding machine (particle size 2-3 mm) for preparation of laboratory samples of stone matrix asphalt (SMA) mixes. They observed that 10% shredded plastic in SMA mix resulted in improvement of Marshall properties, retained stability, indirect tensile strength etc. Yousefi et al. (2009) reported that the polymeric and non-polymeric wastes such as low molecular weight polyethylene (LMP) and N-methylpyrrolidone NMP) wastes of HDPE plants styrene-butadiene rubber (SBR) of BD-SR plants of Bandar Imam Complex in Iran were used to modify bitumen. From the experimental results, they concluded that NMP can act as an extender for bitumen, whereas LMP and SBR wastes are very good bitumen modifiers at moderate and high temperatures. 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.

3 Experimental Investigations

3.1 Materials used

3.1.1 Aggregates

The coarse aggregates and fine aggregates collected from local sources are of granite based and had specific gravities of 2.7 and 2.6 respectively. Fly ash collected from a nearby power plant was used as filler which had a specific gravity of 2.2. For preparation of Marshall specimens, aggregates are used as per grading given in Table 1 based on specifications of MORTH (2006) for bituminous concrete.

Table 1 Gradation of Aggregates

Sieve Size, mm	Specified % Passing	Adopted % Passing
26.5	100	100
19	79-100	90
13.2	59-79	70
9.5	52-72	62
4.75	35-55	45
2.36	28-44	36
1.18	20-34	27
0.60	15-27	21
0.30	10-20	15
0.15	5-13	9
0.075	2-8	5

3.1.2 Bitumen

Bitumen used in preparation of Marshall samples in the laboratory was of 80/100 penetration grade collected from nearby depot. It had a specific gravity of 1.02, penetration of 89 dmm and softening point of 44.5^0C.

3.1.3 Polyethylene used

The polyethylene (PE) used in packaging of a very reputed and popular brand of packaged milk trademarked as Orissa Milk Federation (OMFED) was used as raw material as an additive to aggregates for preparation of bituminous mixes in the laboratory. These polyethylene packets were collected, thoroughly washed and cleaned with detergent and then dried under sunlight. The specific gravity of polyethylene was found to be 0.905. Before using in bituminous mixes the dried polyethylene packets were cut into tiny pieces of small sizes about 2mm x 2mm. Figures 1 and 2 show respectively the normal OMFED packets and shredded OMFED packets.

Figure 1. Normal OMFED Packet as locally available

Figure 2. Shredded forms of locally available OMFED Packets

3.2 Preparation of Marshal Specimens

The Marshall specimens of bituminous concrete mixes are prepared as per the standard procedure laid out in ASTM (1989) specifications. It is to be noted that the required quantity of shredded polyethylene was added to the hot aggregates gradually and mixed manually for some time till a homogenous mix was observed physically. The calculated amount of bitumen at required temperature was added to the aggregate-PE mix and mixed manually till a homogenous mix is produced. The procedure otherwise remains the same as for the unmodified mixes for preparation of Marshall specimens. Initial trials with bitumen resulted 5% bitumen as optimum. Hence, in all tests presented, the bitumen content has been kept constant at 5% and only the PE content has been varied in the mix. Figure 3 shows some of the Marshall specimens cast which are ready for subsequent testing.

Figure 3. Few Prepared Marshall Samples

3.3 Tests conducted

3.3.1 Marshall test

Marshall mix design (ASTM, 1989) is a standard laboratory method, which is adopted in India for determining and reporting the strength and flow characteristics of bituminous paving mixes. In the absence of modern equipments, this method was used to study various Marshall characteristics such as Marshall stability, flow value, unit weight, air voids etc.

3.3.2 Indirect tensile test

This test has been carried out both under static conditions carried out as per (ASTM 2007) and is used to determine the tensile strength of SMA mixes. The tensile strength of the specimen was calculated by using the formula given in ASTM (2007) and mentioned in Eq. (1). This test has been conducted for Marshall specimens at 25^0C. As per this test, a cylindrical Marshall specimen is loaded at a rate of 51mm/min circumferentially through two loading strips each 13mm wide in a diametral plane and the maximum load at failure is noted.

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \qquad (1)$$

where,

S_t = Indirect Tensile Strength, kPa
P = Maximum Load, N
t = Specimen height before testing, mm
D = Specimen Diameter, mm

4 Analysis of Test Results and Discussions

4.1 Marshall Properties

As a first step, Marshall samples were prepared using BC mixes prepared with various PE concentrations with the objective obtaining the optimum PE requirements for a given mix made with 5% bitumen content, and also of studying the Marshall characteristics of all such mixes. The results of the Marshall tests carried out on all such mixes are presented and discussed below.

Figure 3 shows the variations of Marshall stability value with PE content. It is observed that the stability value increase slowly with PE content in the mix that there is a bump in the stability value at 4% PE content. As seen in Figure 4, the flow value decreases with increase in PE content in the mix, a notable feature thus making the mix stiffer. As per MORTH specifications a minimum stability value of 9.0 kN and a flow value of 2 mm to 4 mm are recommended and hence for all PE concentrations tried these two Marshall properties are satisfied.

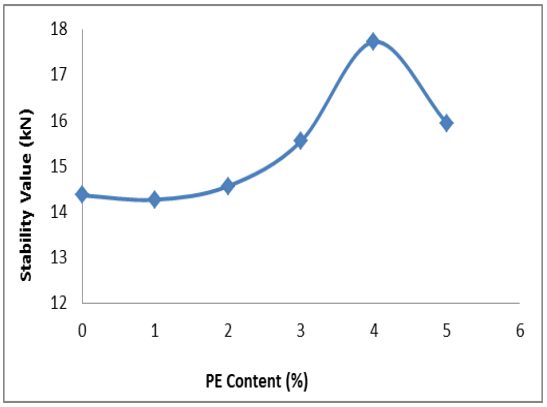

Figure 3. Variation of Marshall Stability value with PE content in Mix

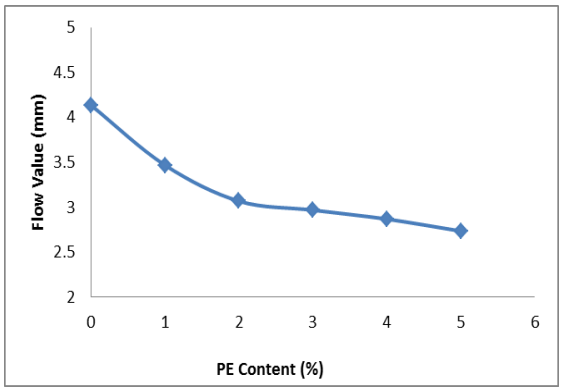

Figure 4. Variation of Flow value with PE content in Mix

The variations of unit weight and air voids value at different PE concentrations presented in Figures 5 and 6 respectively show the similar normal trends. The unit weight and air voids decrease with PE content. The minimum requirement of air voids is satisfied up to PE content of 4%. As seen in Fig.7, the minimum VMA requirement is satisfied for all PE concentrations tried in the mix.

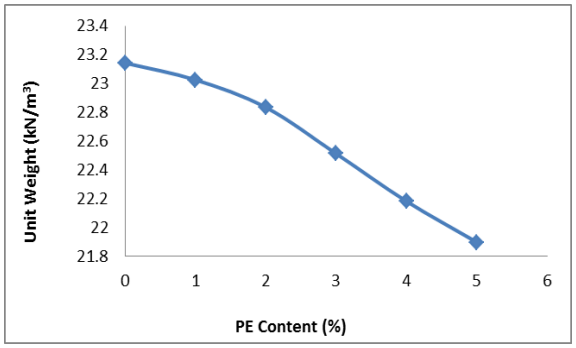

Figure 5. Variation of Unit weight with PE content in Mix

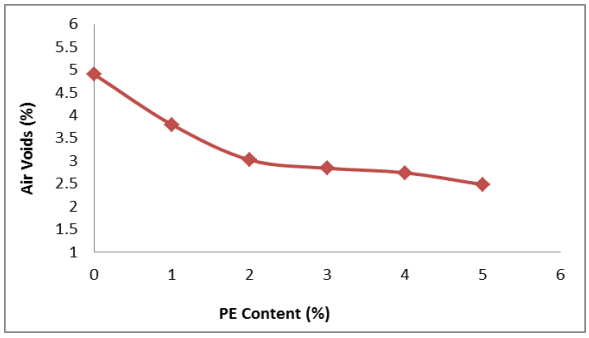

Figure 6. Variation of Air voids with PE content in Mix

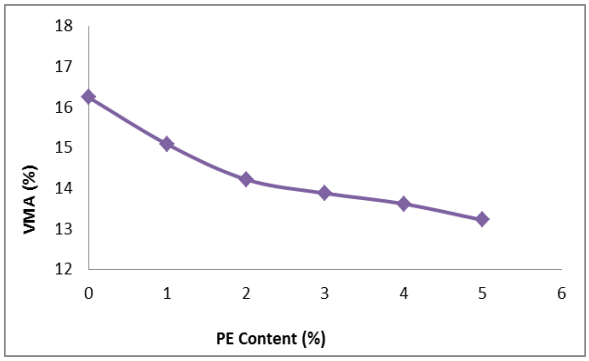

Figure 7. Variation of VMA with PE content in Mix

4.2 Static Indirect Tensile Test

Figure 8 shows the variation of indirect tensile strength (ITS) at 25^0C with PE concentration in the mix. It is seen that the ITS value increases with increase in PE concentration up to 4% in the mix after which this decreases more or less as in the case of Marshall stability values.

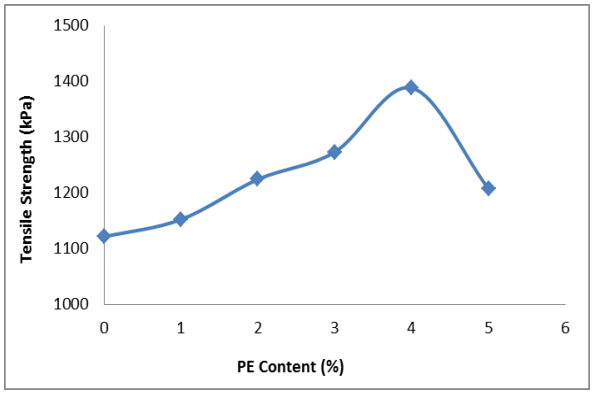

Figure 8. Variation of ITS with PE content in Mix

5 Conclusions

The plastic waste is a menace to the environment, the effective disposal of which is a concern to everyone. Out of all plastic wastes only a certain percentage is recycled, while the major component needs to be disposed of effectively. The packaging mostly made of low density polyethylene is major component of plastic wastes. For making sustainable pavements the paving industry at this age is frequently utilising bitumen modified by several polymers out of which low density polyethylene has been found to be quite effective. The present investigation provides a scope of effectively using LDPE based packets widely used for packing very popular brand of powdered milk which is generally thrown as wastes after their use by the households or others, thus not only partly solving the environmental problems of a civilised society in respect of disposal, but also enhancing the properties of the paving mixes for effectively catering to the excessive and heavy traffic demand.

Marshall test being commonly practiced in India has been attempted in the laboratory to determine the optimum PE concentration in a bituminous concrete mix. In general the addition of PE in shredded form to aggregates increases the stability value, and reduces the other Marshall properties. Satisfying all the Marshall criteria, it is observed that addition of 3-4% PE brings in substantial improvement in Marshall characteristics. Like Marshall stability, the indirect tensile strength of SMA mixes is observed to increase with increase in PE content in the mix up to PE content of 4%.

This laboratory study in a limited scale explains that there is enough scope of using polyethylene packets used for packaging milk powder in a shredded form, such packets being abundantly and easily available in the environment with aggregates in preparation of paving mixes. This can help in effective use of waste materials for construction of improved bituminous flexible pavements in important roads or highways with heavy demand of traffic.

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