

Study on the Use of Waste Polyethylene in Asphalt Pavements

¹Anupama, ²Swati Agrawal

¹M.Tech Student, Department of Civil Engineering, Kalinga University Raipur (CG), India

²Assistant Professor, Department of Civil Engineering, Kalinga University Raipur (CG), India

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract: The growing accumulation of plastic waste, particularly polyethylene, poses significant environmental challenges. This study investigates the feasibility of incorporating waste polyethylene into asphalt mixtures as a sustainable solution for both waste management and pavement improvement. Laboratory experiments were conducted to evaluate the performance characteristics of asphalt modified with varying proportions of shredded waste polyethylene. Key performance indicators such as Marshall Stability, flow value, rutting resistance, and moisture susceptibility were analyzed. The results indicate that the addition of polyethylene enhances the mechanical properties of the asphalt mix, including increased stiffness and improved resistance to deformation. Moreover, the use of plastic-modified asphalt contributes to reduced environmental impact and promotes the circular economy in road construction. This research supports the potential of waste polyethylene as a viable additive in asphalt pavements, offering economic and ecological benefits.

Keywords: Waste polyethylene, plastic-modified asphalt, asphalt pavement, sustainable construction, Marshall Stability, rutting resistance, environmental impact, circular economy.

I. Introduction

Bituminous binders are widely used by paving industry. In general pavements are categorized into 2 groups, i.e. flexible and rigid pavement.

Flexible Pavement

Flexible pavements are those, which on the whole have low flexural strength and are rather flexible in their structural action under loads. These types of pavement layers reflect the deformation of lower layers on-to the surface of the layer.

Rigid Pavement

If the surface course of a pavement is of Plain Cement Concrete then it is called as rigid pavement since the total pavement structure can't bend or deflect due to traffic loads. Pavement design and the mix design are two major considerations in case of pavement engineering. The present study is only related to the mix design of flexible pavement considerations. The design of asphalt paving mixtures is a multi-step process of selecting binders and aggregate materials and proportioning them to provide an appropriate compromise among several variables that affect mixture behaviour, considering external factors such as traffic loading and climate conditions.

1.1 Requirements of bituminous mixes

Bituminous mixture used in construction of flexible pavement should have following properties;

- Stability
- Durability
- Flexibility
- Skid resistance
- Workability

1.2 Waste plastic: the problem

Today availability of plastic waste is enormous. The use of plastic materials such as carry bags, cups, etc is constantly increasing. Nearly 50% to 60% of total plastic are consumed for packing. Once used, plastic packing materials are thrown outside and they remain as waste. Plastic wastes are durable and non-biodegradable. The improper disposal of plastic may cause breast cancer, reproductive problems in humans and animals, genital abnormalities and much more. These plastic wastes get mixed with water, disintegrate, and take the forms of small pellets which cause the death of fishes and other aquatic life who mistake them as food material. Sometimes they are either land filled or incinerated. Plastic wastes get mixed with the municipal solid waste or thrown over a land area. All the above processes are not eco-friendly as they pollute the land, air and water. Under these circumstances, an alternative use of these plastic wastes is required. So any method that can use this plastic waste for purpose of construction is always welcomed.

1.3 Role of polyethylene in bituminous pavements

Use of polyethylene in road construction is not new. Some aggregates are highly hydrophilic (water loving). Like bitumen polyethylene is hydrophobic (water hating) in nature. So the addition of hydrophobic polymers by dry or wet mixing process to asphalt mix lead to improvement of strength, water repellent property of the mix. Polyethylenes get added to hot bitumen mixture and the mixture is laid on the road surface like a normal tar road. Plastic roads mainly use plastic carry-bags, disposable cups, polyethylene packets and PET bottles that are collected from garbage as important ingredients of the construction material. Polymer modification can be considered as one of the solution to improvise the fatigue life, reduce the rutting & thermal cracking in the pavement. Creating a modified bituminous mixture by using recycled polymers (e.g., polyethylene) which enhances properties of HMA mixtures would not only produce a more durable pavement, but also provide a beneficial way of disposal of a large amount of recycled plastics.

1.4 Objectives of present investigation

A comparative study has been made in this investigation between SMA, BC, and DBM mixes with varying binder contents (3.5% - 7%) and polyethylene contents (0.5% - 2.5%). The objectives of this investigation are to observe the followings;

- Study of Marshall properties of mixes using both
 1. Stone dust as filler and,
 2. Slag as fine aggregate and fly ash as filler.
- The effect of polyethylene as admixture on the strength of bituminous mix with different filler and replacing some percentage of fine aggregate by slag.
- The performance of bituminous mix under water with and without polyethylene admixture with different filler and replacing some percentage of fine aggregate by slag.
- To study resistance to permanent deformation of mixes with and without polyethylene.
- Evaluation of SMA, BC, and DBM mixes using different test like Drain down test, Static Indirect tensile Strength test, Static Creep test etc.

2.Literature Review

i. 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. Their results indicated that flexible pavement with high performance and durability can be obtained with 10% shredded plastic.

ii. Fernandes et al. (2008) studied Rheological evaluation of polymer modified asphalt binders by using thermoplastic elastomer styrene butadiene styrene (SBS) and they compared the properties of Modified binder by addition of both oil shale and aromatic oil to improve their compatibility. The rheological characteristics of the SBS PMBs were analyzed in a dynamic shear rheometer (DSR) and the morphology accessed by fluorescence optical microscopy. The results indicated that the aromatic and shale oils have similar effects on the microstructure, storage stability and viscoelastic behaviour of the PMBs. Thus, shale oil could be successfully used as a compatibilizer agent without loss of properties or could even replace the aromatic oil.

iii. Awwad and Shbeeb (2007) indicated that the modified mixture has a higher stability and VMA percentage compared to the non-modified mixtures and thus positively influence the rutting resistance of these mixtures. According to them modifying asphalt mixture with HDPE polyethylene enhances its properties far more than the improvements realized by utilizing LDPE polyethylene.

iv. Gawande et al. (2012) gave an overview on waste plastic utilization in asphalt road by using both wet and dry method. They said that use of modified bitumen with the addition of processed waste plastic of about 5-10% by weight of bitumen helps in improving the longevity and pavement performance with marginal saving in bitumen usage and according to them use of waste plastics in the manufacture of roads and laminated roofing also help to consume large quantity of waste plastics. Thus, these processes are socially highly relevant, giving better infrastructure.

v. Khan and Gundaliya (2012) stated that the process of modification of bitumen with waste polythene enhances resistance to cracking, pothole formation and rutting by increasing softening point, hardness and reducing stripping due to water, thereby improving the general performance of

roads over a long period of time. According to them the waste polythene utilized in the mix forms coating over aggregates of the mixture which reduces porosity, absorption of moisture and improves binding property.

vi. Prusty (2012) studied the behaviour of BC mixes modified with waste polythene. He used various percentages of polythene for preparation of mixes with a selected aggregate grading as given in the IRC Code. Marshall Properties such as stability, flow value, unit weight, air voids are used to determine optimum polythene content for the given grade of bitumen (80/100) in his study. Considering these factors he observed that a more stable and durable mix for the pavements can be obtained by polymer modifications.

vii. Swami et al. (2012) investigated that the total material cost of the project is reduced by 7.99% with addition of plastic to bitumen between the ranges of 5% to 10%. They concluded that by modification of bitumen the problems like bleeding in hot temperature regions and sound pollution due to heavy traffic are reduced and it ultimately improves the quality and performance of road.

viii. Pareek et al. (2012) carried out experimental study on conventional bitumen and polymer modified binder and observed a significant improvement in case of rutting resistance, indirect tensile strength and resilient modulus of the bituminous concrete mix with polymer modified bitumen. They also concluded that Polymer modified bitumen results a high elastic recovery (79%) and better age resistance properties (The loss in weight on heating in thin film oven is 6 times higher as compared to conventional bitumen of 60/70).

ix. 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.

x. Sabina et al. (2009) evaluated the performance of waste plastic/polymer modified bituminous mix and observed that the results of Marshall stability and retained stability of polythene modified bituminous concrete mix increases 1.21 and 1.18 times higher than that of conventional mix by using 8% and 15% (by weight of bitumen) polythene with respect to 60/70 penetration grade of bitumen. But modified mix with 15% polyethylene showed slightly decreased values for Marshall Stability than that of the mix with 8% modifier in their results.

3. Methodology

3.1 Constituents of a mix

Bituminous mix consists of a mixture of aggregates continuously graded from maximum size, typically less than 25 mm, through the fine filler that is smaller than 0.075mm. Sufficient bitumen is added to the mix so that the compacted mix is effectively impervious and will have acceptable dissipative and elastic properties. The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical.

The basic materials used are as follows:

- Aggregates
- Fly Ash
- Slag
- Bituminous Binder
- Polyethylene

3.2 Fly Ash

At present, as per the report of the Fly Ash Utilisation Programme (FAUP), out of the huge quantity of fly ash produced, only about 35% finds its use in commercial applications such as mass concrete, asphalt paving filler, lightweight aggregate, stabilizer to road bases, raw material for concrete, additives to soil, construction of bricks etc. The remainder fly ash is a waste requiring large disposal area, causing a huge capital loss to power plants and simultaneously causing an ecological imbalance and related environmental problems (Dhir, 2005). In this investigation fly ash is used as one type of filler.

3.3 Granulated blast furnace slag

Granulated blast furnace slag (GBFS) is a by-product obtained in the manufacture of pig iron in the blast furnace and is formed by the combination of iron ore with limestone flux. If the molten slag is cooled and solidified by rapid water quenching to a glassy state, it results granulated blast furnace slag of sand size fragments, usually with some friable clinker- like material. The physical structure and gradation of granulated slag depend on the presence of chemicals such as lime, alumina, silica and magnesia, whose percentages may vary depending on the nature of iron ore, the composition of limestone flux and the kind of iron being produced. In present study granulated blast furnace slag is used as fine aggregates by replacing some gradation of natural aggregates.

3.4 Bituminous Binder

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in bituminous mixtures. Bitumen must be treated as a visco-elastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. At low temperature it behaves like an elastic material and at high temperatures its behaviour is like a viscous fluid. Asphalt binder VG30 is used in this research work. Grade of bitumen used in the pavements should be selected on the basis of climatic

conditions and their performance in past. It fills the voids, cause particle adhesion and offers impermeability.

Table 3.1: Physical properties of coarse aggregates

Property	Test Method	Test Result
Aggregate Impact Value (%)	IS: 2386 (P IV)	14.3
Aggregate Crushing Value (%)	IS: 2386 (P IV)	13.02
Los Angels Abrasion Value (%)	IS: 2386 (P IV)	18
Flakiness Index (%)	IS: 2386 (P I)	18.83
Elongation Index (%)	IS: 2386 (P I)	21.5
Water Absorption (%)	IS: 2386 (P III)	0.1

3.5 Binder

One conventional commonly used bituminous binder, namely VG 30 bitumen was used in this investigation to prepare the samples. Conventional tests were performed to determine the physical properties of these binders.

Table 3.2: Physical properties of binder

Property	Test Method	Value
Penetration at 25 °C (mm)	IS : 1203-1978	67.7
Softening Point (°C)	IS : 1203-1978	48.5
Specific gravity	IS : 1203-1978	1.03

3.6 Static indirect tensile strength test

In this test, a compressive load of 51 mm/minute is applied on a cylindrical Marshall specimen along a vertical diametrical plane through two curved strips made up of stainless steel, whose radius of curvature is same as that of the specimen. The sample was kept in the Perspex water bath maintained at the required temperature for minimum 1/2 hours before test, and the same temperature was maintained during test. This loading configuration developed a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametric plane and the specimen failed by splitting along the vertical diameter.

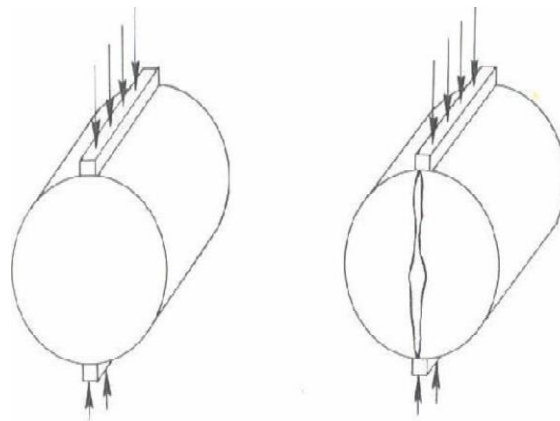


Fig. 3.1 Loading configuration for indirect tensile strength test

4. Results

This chapter deals with test results and analysis carried out in previous chapter. This chapter is divided into four sections. First section is deals with parameter used for analysis of different test results. Second section deals with calculation and comparison of optimum binder content (OBC) and optimum polyethylene content (OPC) of SMA, BC, and DBM mixes with and without polyethylene with stone dust used as filler. Third section deals with calculation and comparison of Optimum binder Content (OBC) and Optimum polyethylene content (OPC) of SMA, BC, and DBM mixes with or without polyethylene by replacing some gradation of fine aggregate by granulated blast furnace slag with fly ash as filler. Fourth section deals with analysis of test results of drain down test, static indirect tensile and static creep test at different test temperature.

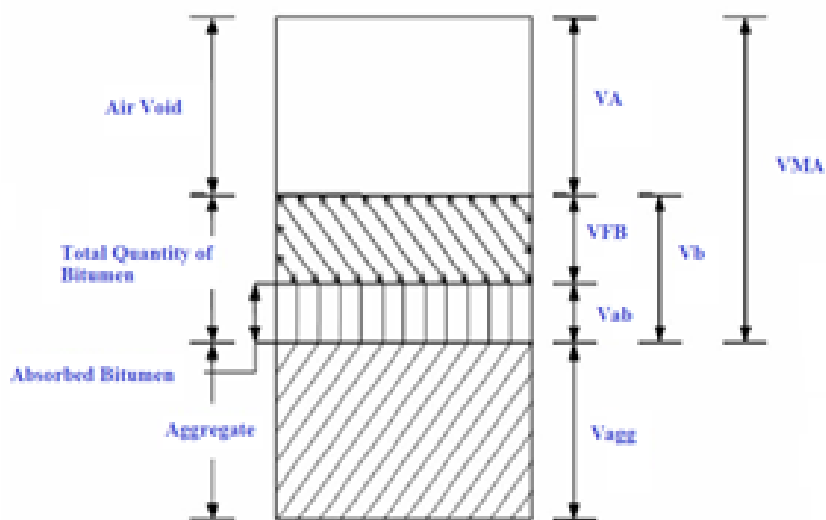


Fig.-4.1 Phase diagram of bituminous mix

4.1 Marshall stability

It is observed from graphs that with increase in bitumen concentration the Marshall stability value increases up to certain bitumen content and there after it decreases. That particular bitumen content is called as optimum binder content (OBC). In present study OBC for conventional SMA, BC, and DBM mixes are found as 6%, 4.5%, and 4.5% and similarly OBC are found as 4% for modified SMA, BC and DBM mixes with polyethylene at different concentration. From the graphs it can be observed that with addition of polyethylene stability value also increases up to certain limits and further addition decreases the stability. This may be due to excess amount of polyethylene which is not able to mix in asphalt properly. That polyethylene concentration in mix is called optimum polyethylene content (OPC) which is found as 2% for SMA and DBM and 1.5% for BC mixes.

4.2 Retained stability

Retained stability is calculated for SMA, BC, and DBM mixes for both of with polyethylene and without polyethylene. It is observed that the addition of polyethylene to the mixture the retained stability value increases. It is analyzed that the BC with polyethylene results in highest retained stability followed by DBM with polyethylene and then SMA with polyethylene.

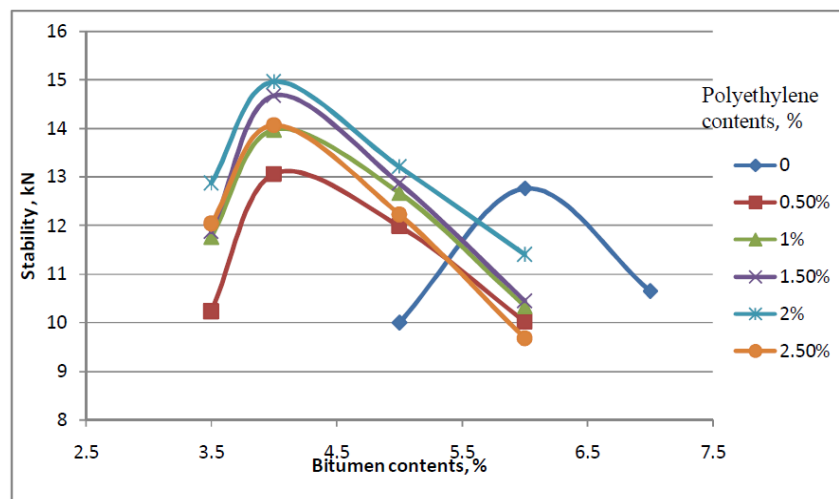


Fig 4.2 Variations of Marshall Stabilities of SMA with different binder and polyethylene

Contents

4.3 Marshall stability

It is observed from graphs that after replacement of fine aggregate by slag and filler by fly ash OBC for SMA, BC, and DBM mixes are found as 6%, 4.5%, and 4.5% and similarly OBC are found as 5% for modified SMA mixes and 4% for modified BC and DBM mixes with polyethylene at different concentration. OPC has been found as 1.5% of polyethylene for all types of modified mixes with fly ash and slag. From graphs it is found that bituminous mixes with fly ash and slag have same OBC as conventional mixes, resulting higher stability values. But OBC values decrease for BC and DBM and increases for SMA in case of polymer modified bituminous mixture with slag and fly ash in comparison to OBC of modified bituminous mixture with stone dust.

5. Conclusion

In this study, three types of mixes i.e. SMA, DBM and BC are prepared with VG30 grade bitumen used as a binder. The effect of addition of waste polyethylene in form of locally available artificial milk with brand OMFED packets in the bituminous mixes has been studied by varying concentrations of polyethylene from 0% to 2.5% at an increment of 0.5%.

Using Marshall Method of mix design the optimum bitumen content (OBC) and optimum polyethylene content (OPC) have been determined for different types of mixes. It has been observed that addition of 2% polyethylene for SMA and DBM mixes and 1.5% polyethylene for BC mixes results in optimum Marshall Properties where stone dust is used as filler. But when small fraction of fine aggregates are replaced by granulated blast furnace slag and filler is replaced by fly ash, optimum Marshall Properties for all types of mixes result with only 1.5% polyethylene addition. The OBCs in case of modified SMA, BC and DBM mixes by using stone dust as filler are found 4% and OBCs in case of modified (i) SMA, and (ii) BC, and DBM by using fly ash and slag are found to be 5% and 4% respectively.

Using the same Marshall specimens prepared at their OPCs and OBCs by using both (i) stone dust as filler and (ii) replacing of stone dust by fly ash and fine aggregate by slag, for test under normal and wet conditions it is observed that the retained stability increases with addition of polyethylene in the mixes, and BC with polyethylene results in highest retained stability followed by DBM with polyethylene and then SMA with polyethylene.

Addition of polyethylene reduces the drain down effect, though these values are not that significant. It may be noted that the drain down of SMA is slightly more than BC without polyethylene. However, for all mixes prepared at their OPC there is no drain down.

In general, it is observed that the Indirect Tensile Strength (ITS) value decreases with increase in temperature and for a particular binder, when polyethylene gets added to the mixes the value further increases in both cases. The BC mixes with polyethylene result in highest indirect tensile strength values compared to SMA, followed by DBM.

It is observed that by addition of polyethylene to the mixture, the resistance to moisture susceptibility of mix also increases. BC with polyethylene results in highest tensile strength ratio followed by DBM mixes with polyethylene and SMA mixes with polyethylene for both cases.

References

- [1] AASHTO T 283, "Standard method of test for resistance of compacted asphalt mixtures to moisture-induced damage", *American association of state highway and transportation officials*.
- [2] AASHTO T 305, "Drain-down characteristics in un-compacted asphalt mixtures", *American association of state highway and transportation officials*.
- [3] Ahmadiania E., Zargar M., Karim M. R., Abdelaziz M. and Ahmadiania E. (2012), "Performance evaluation of utilization of waste Polyethylene Terephthalate (PET) in stone mastic asphalt", *Journal of Construction and Building Materials, Volume 36*, pp. 984–989.
- [4] Airey G. D., Rahimzadeh B. and Collop A. C. (2004), "Linear rheological behaviour of bituminous paving materials", *Journal of materials in civil engineering, Volume 16*, pp. 212-220.

- [5] Al-Hadidy A.I. and Yi-qiu T. (2009), “Effect of polyethylene on life of flexible pavements”, *Journal of Construction and Building Materials*, volume 23, pp. 1456– 1464.
- [6] ASTM D 1559, “Test method for resistance of plastic flow of bituminous mixtures using Marshall Apparatus”, *American society for testing and materials*.
- [7] ASTM D 6931 (2007), “Indirect Tensile (IDT) Strength for bituminous mixtures”, *American society for testing and materials*.
- [8] ASTM D 792-08, “Standard test methods for density and specific gravity of plastic by displacement”, *American society for testing and materials*.
- [9] ASTM D882–12, “Standard test method for tensile properties of thin plastic sheeting”, *American society for testing and materials*.
- [10] Attaelmanan M., Feng C. P. and AI A. (2011), “Laboratory evaluation of HMA with high density polyethylene as a modifier”, *Journal of Construction and Building Materials, Volume 25*, pp. 2764–2770.
- [11] Awwad M. T. and Shbeeb L (2007), “The use of polyethylene in hot asphalt mixtures”, *American Journal of Applied Sciences, volume 4*, pp. 390-396.
- [12] Bindu C.S., Beena K.S. (2010), “Waste plastic as a stabilizing additive in SMA”, *International Journal of Engineering and Technology, Volume 2*, pp. 379-387.
- [13] Casey D., McNally C., Gibney A. and Gilchrist M. D. (2008), “Development of a recycled polymer modified binder for use in stone mastic asphalt”, *Journal of Resources, Conservation and Recycling, Volume 52*, pp. 1167–1174.
- [14] Chen (2008/09), “Evaluated rutting performance of hot mix asphalt modified with waste plastic bottles”.
- [15] Das A. and Chakroborty P. (2010), “Principles of Transportation Engineering”, *Prentice Hall of India, New Delhi, pp 294-299*.