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Effect of Polyethylene Modification on the Mechanical Properties of Asphalt Mixtures

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***Abstract* - Asphalt mixtures are widely used in the construction of flexible pavements due to their cost-effectiveness and ease of construction. However, their mechanical performance can deteriorate under conditions such as heavy traffic loads, temperature variations, and moisture exposure. To enhance performance, this study investigates the effect of polyethylene modification on the mechanical properties of asphalt. Reclaimed polyethylene, sourced from locally available milk packaging (OMFED), was used as a polymer additive in three types of asphalt mixes: Bituminous Concrete (BC), Dense Bituminous Macadam (DBM), and Stone Mastic Asphalt (SMA). The study determined the Optimum Binder Content (OBC) and Optimum Polyethylene Content (OPC) for each mix using the Marshall method. The OBC for mixes with stone dust filler was 4%, while the use of granulated blast furnace slag and fly ash as fillers resulted in OBCs of 5% for SMA and 4% for BC and DBM. The OPC was found to be 2% for SMA and DBM, and 1.5% for BC when using stone dust; for mixes with slag and fly ash, the OPC was 1.5% across all types. Performance evaluation through drain down tests, static indirect tensile strength tests, and static creep tests revealed that the inclusion of polyethylene significantly improves key mechanical properties of the asphalt mixes. The modified mixes showed enhanced Marshall Stability, reduced binder drain down, and better resistance to deformation and cracking, indicating that polyethylene is an effective stabilizing additive in asphalt pavements.**

Keywords: Asphalt Modification, Polyethylene, Bituminous Concrete (BC), Stone Mastic Asphalt (SMA), Dense Bituminous Macadam (DBM), Marshall Properties, Tensile Strength, Creep Test.

I. INTRODUCTION

1.1 General

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.

1.2 Bituminous Mix Design

1.2.1 Overview

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. There are two types of the mix design, i.e. dry mix design and wet mix design

1.2.2 Objective of Bituminous Mix Design

Main objectives of bituminous mix design are to find;

- Optimum bitumen content to ensure a durable pavement,
- Sufficient strength to resist shear deformation under traffic at higher temperature,
- Proper amount of air voids in the compacted bitumen to allow for additional compaction done by traffic,
- Sufficient workability, and

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- Sufficient flexibility to avoid cracking due to repeated traffic load.

1.3 Polymer Modification

1.3.1 Present Scenario

Bituminous binders are widely used in road paving and their visco-elastic properties are dependent on their chemical composition. Now-a-days, the steady increment in high traffic intensity in terms of commercial vehicles, and the significant variation in daily and seasonal temperature put us in a situation to think about some alternative ways for the improvement of the pavement characteristics and quality by applying some necessary modifications which shall satisfy both the strength as well as economical aspects. Bitumen can also be modified by adding different types of additives to achieve the present requirement. One of these additives is the polymers.

1.3.2 Waste Plastic: The Problem

Plastic garbage is widely available nowadays. The use of plastic products such as carry bags, mugs, and so on is expanding all the time. Packing accounts for roughly 50% to 60% of overall plastic consumption. Plastic packaging materials are discarded after they have been utilized. Plastic garbage is long-lasting and non-biodegradable. Plastic waste disposal can lead to breast cancer, reproductive issues in people and animals, genital deformities, and other difficulties. These plastic wastes combine with water, dissolve, and take the form of miniature pallets, killing fish and other aquatic animals that mistake them for food. They are sometimes either landfilled or burnt. Plastic garbage is mixed with municipal solid refuse or tossed on the ground.

1.4 Objective

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.

II. LITERATURE REVIEW

2.1 Studies on Use of Waste Polyethylene in Paving Mixes

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

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 compatibly. 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.

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.

Gawande et al. (2012) gave an overview on waste plastic utilization in asphalting 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.

Khan and Gundaliya (2012) stated that the process of modification of bitumen with waste polythene enhances resistance to cracking, pothole formation and rutting by

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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.

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.

III. RAW MATERIALS

3.1 Constituents of a Mix

Bituminous mix comprises continuously graded aggregates (max. size <25 mm) with bitumen to make the mix impervious and durable. The design goal is to determine optimal proportions of bitumen, filler, fine and coarse aggregates for strength, workability, durability, and economy. The materials used include:

- **Aggregates:** Aggregates make up 90–95% of mix weight and provide strength. They are of three types:
    - **Coarse Aggregates:** Retained on 4.75 mm sieve, provide strength and interlocking. Stone chips with specific gravity 2.75 are used.
    - **Fine Aggregates:** Pass 4.75 mm and retained on 0.075 mm sieve, fill voids and stiffen binder. Quarry dust and slag with specific gravity 2.6 and 2.45 are used.
    - **Filler:** Pass 0.075 mm sieve, fill voids and improve impermeability. Fly ash and stone dust with specific gravity 2.3 and 2.7 are used.
- **Fly Ash:** A waste by-product of thermal plants, only ~35% is reused. It is used here as a filler to improve sustainability.
- **Granulated Blast Furnace Slag (GBFS):** A by-product from pig iron production, cooled rapidly to form glassy sand-like particles. Used as fine aggregate replacement.
- **Bituminous Binder:** Bitumen (VG30) acts as a binding agent. Exhibits elastic behavior at low temperatures and viscous at high. It ensures cohesion and water resistance.
- **Polyethylene:** Used as a stabilizing additive to enhance binder properties and pavement performance.

3.2 Materials

Aggregates: Aggregates conforming to MORTH gradation were used for SMA, DBM, and BC mixes. VG30 binder and polyethylene were added per Marshall Method. Specific gravity and other physical properties are provided in Tables 3.4 and 3.5.

Table 3.1: Gradation of Aggregates for SMA

Sieve Size (mm)	Percentage Passing
19	100
13.2	94
9.5	62
4.75	28
2.36	24
1.18	21
0.6	18
0.3	16
0.075	10

Table 3.2: Gradation of Aggregates for BC

Sieve Size (mm)	Percentage Passing
19	100
13.2	79-100
9.5	70-88
4.75	53-71
2.36	42-58
1.18	34-48
0.6	26-38
0.3	18-28
0.15	12-20
0.075	4-10

Table 3.3: Gradation of Aggregates for DBM

Sieve Size (mm)	Percentage Passing
37.5	100
26.5	90-100
19	71-95
13.2	56-80
9.5	-
4.75	38-54
2.36	28-42
1.18	-
0.6	-
0.3	7-21
0.15	-
0.075	2-8

Table 3.4: Specific Gravity of Aggregates

Types of Aggregates	Specific Gravity
Coarse	2.75
Fine (Stone)	2.6
Fine(Slag)	2.45
Filler(Stone Dust)	2.7

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Filler(Fly Ash)	2.3

Table 3.5: 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

3.2.2 Fly Ash & Slag

Both the fly ash and slag used in present investigation are collected from Bhilai steel plant. The chemical composition and XRD results are given in Table 3.6.

Table 3.6: Chemical Composition of Fly Ash and Slag in Percentage (By Weight)

Constituents	Fly Ash	Slag
Fe_2O_3	10.3%	4.012%
CaO	4.206%	26.638%
MgO	3.023%	16.124%
Sillica	56.4%	32.14%
Al_2O_3	29%	21%
Carbon	7.18%	0%

Figure 3.3: OMFED Polyethylene Used

Table 3.7: Physical Properties of Polyethylene Used

Properties	Results
Specific Gravity	0.905
Softening Point	54.22°C
Young Modulus	109.75 Mpa
Strain At Break	1351 %
Strain At Peak	1271.5 %
Displacement At Break	135.15 Mm
Displacement At Peak	127.15 Mm
Load At Peak	.0146 Kn
Stress at peak	Mpa

IV. EXPERIMENTAL WORK

4.1.1 Determination of Specific Gravity of Polyethylene

Specific gravity of polyethylene was found out by following the guidelines of ASTM D792-08.

The procedure adopted is given below;

- The weight of the polyethylene in air was measured by a balance. Let it be denoted by “a”.
- An immersion vessel full of water was kept below the balance.
- A piece of iron wire was attached to the balance such that it is suspended about 25 mm above the vessel support.
- The polyethylene was then tied with a sink by the iron wire and allowed to submerge in the vessel and the weight was measured. Let it be denoted as “b”.
- Then polyethylene was removed and the weight of the wire and the sink was measured by submerging them inside water. Let it be denoted as “w”.

The specific gravity is given by

$$\mathbf{s = a / (a + w - b)}$$

Where:

a = Apparent mass of specimen, without wire or sinker, in air
b = Apparent mass of specimen and of sinker completely immersed and of the wire partially immersed in liquid
w = Apparent mass of totally immersed sinker and of partially immersed wire.

From the experiment, it was found that a = 19 gm b = 24 gm w = 26 gm

=> s = 19 / (19+26-24) = 19/21 =0.90476

Take specific gravity of polyethylene = 0.905.

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4.1.2 Determination of Tensile Properties of Polyethylene

The ability to resist breaking under tensile stress is one of the most important and widely measured properties of materials. Tensile strength of polyethylene was calculated by using INSTORN – 1195 CORPORATION with Sample rate = 9.103 pts/sec and Crosshead speed (speed at which sample is stretched) = 50 mm/min. Rectangular Polyethylene samples were prepared according to ASTM D882. Dimension of polyethylene was measured by using digital Vernier caliper (Width = 10mm, Thickness = 0.1mm, Gauge length = 10mm, Grip distance = 40mm). The following results are found out from this test;

Young's modulus (also called as tensile modulus) = $\frac{Stress}{Elastic\ Strain}$ **= 109.75 Mpa**

Strain at break = 1351%
Strain at peak = 1271.5 %
Displacement at break = 135.15mm
Displacement at peak = 127.15 mm Load at peak = .0146 kn

Stress at peak =14.59 Mpa (Stress at peak or ultimate tensile strength or tensile strength at break is the percentage increase in length that occurs under tension before break. If polyethylene possesses high elongation and high ultimate tensile strength it is called as tough).

4.1.3 Determination of Softening Point of Polyethylene

Softening point of polyethylene was determined by using DSC 822, a low temperature differential scanning calorimeter with rate of heating 10 ℃ /mi . The temperature was maintained in between 25 ℃- 80℃ according to melting point of polyethylene. The glass transition temperature is found as 54.22℃ (It the temperature at which phase change occurs and it is the service temperature).

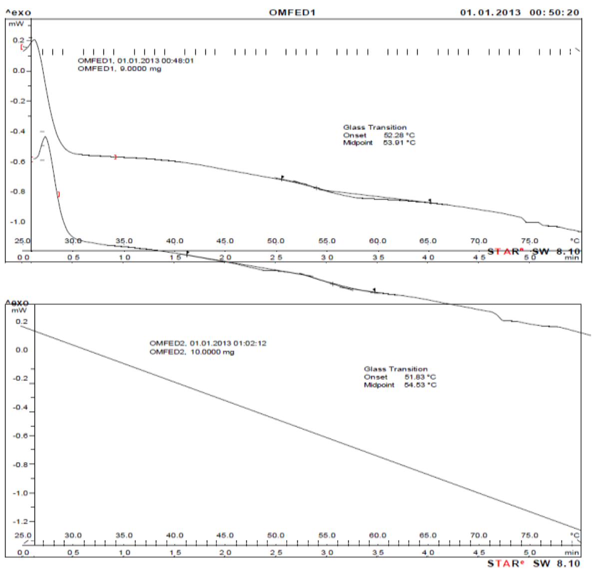

Figure 4.1: Results of Two Set of Polyethylene Samples Given By DSC 822

4.2 Tests on Marshall Samples

4.2.1 Marshall Test

In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm/min. Here are two major features of the Marshall method of mix design.

a) Stability, flow tests and
b) Voids analysis.

The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load. In India, it is a very popular method of characterization of bituminous mixes due to its simplicity and low cost. In the present study the Marshall properties such as stability, flow value, unit weight and air voids were studied to obtain the optimum binder contents (OBC) and optimum polyethylene contents (OPC).

Figure 4.2: Marshall Test in Progress

V. ANALYSIS OF RESULTS AND DISCUSSION

5.1 Effect of Polyethylene Concentration on Marshall Properties of SMA, BC and DBM Mixes with Stone Dust as Filler

Here result in variation of Marshall properties with different binder content where polyethylene content is taken as 0%, 0.5%, 1%, 1.5%, 2% and 2.5% for SMA and DBM and 0%, 0.5%, 1%, 1.5%, 2% for BC are explained below.

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5.1.1 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.

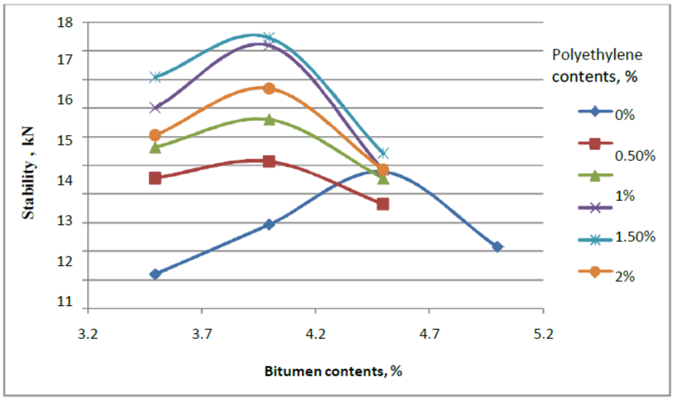

Figure 5.1: Variations of Marshall Stabilities of DBM with Different Binder and Polyethylene Contents

5.1.2 Flow Value

It is observed from graphs that with increase in binder content flow value increases but by addition of polyethylene flow value decreases than that of conventional mixes, again further addition of polyethylene after OPC the flow value stars to increase.

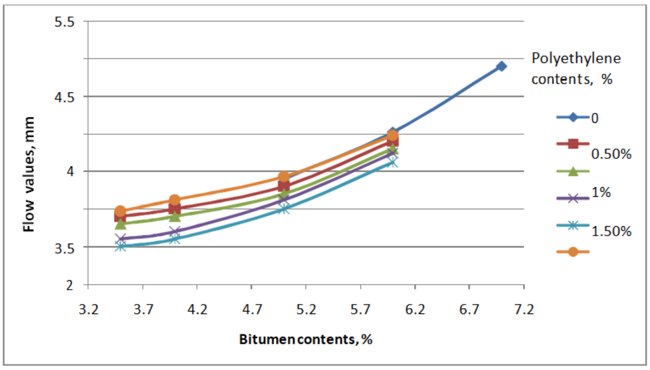

Figure 5.2: Variations of Flows Value of SMA with Different Binder and Polyethylene Content

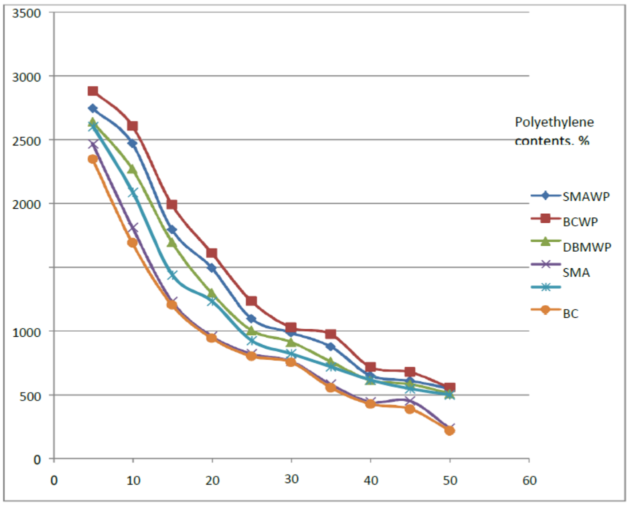

Figure 5.3: Variation of ITS Values of SMA, DBM and BC with Stone Dust as Filler in Different Temperatures

Table 5.1: TSR of Mixes with Stone Dust and With Fly Ash and Slag With and Without Polyethylene

Types of Mixes	Tensile Strength Ratio of Mixes With Stone Dust (%)	Tensile Strength Ratio of Mixes With Fly Ash And Slag (%)	Design Requirement
SMA Without Polyethylene	76.81	80.4	Minimum 80% (as per MORTH Table 500-17
SMA With Polyethylene	82.14	85.4	
DBM Without Polyethylene	79.26	81.6	
DBM With Polyethylene	84.78	87.2	
BC Without Polyethylene	79.68	82.7	
BC With Polyethylene	87.26	89.1	

5.2 Static Creep Test

Static creep test is done to measure permanent deformation of bituminous mixes with and without polyethylene when static load is applied. It is analyzed from the test results that deformation of mix decreases by addition of polyethylene at all temperatures. The mixes with fly ash and slag result smaller deformations values than conventional mixes. It is observed that BC mixes with polyethylene give the minimum value of deformation at OPC and OBC than all others for both mixes with stone dust and mixes with fly ash and slag. Graphs have been plotted between;

a) Time and deformation and,
b) Time and strain.

It is observed from the time Vs stain graphs that BC mixes with polyethylene give the minimum strain as compared to other mixes.

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5.2.1 Deformations of Mixes with Stone Dust Used As Filler

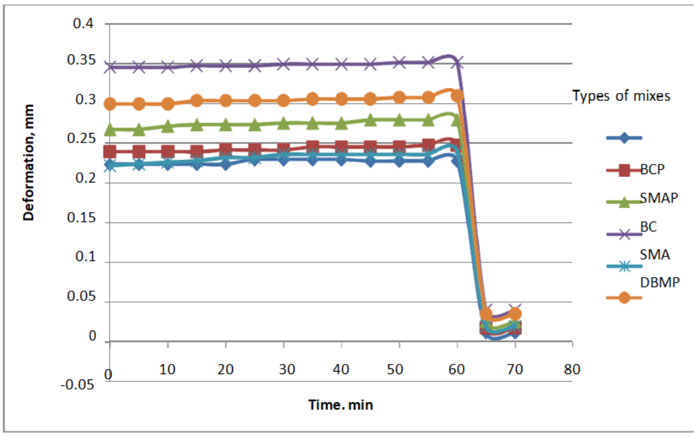

Figure 5.4: Deformation Values at 30 °C for SMA, BC, and DBM

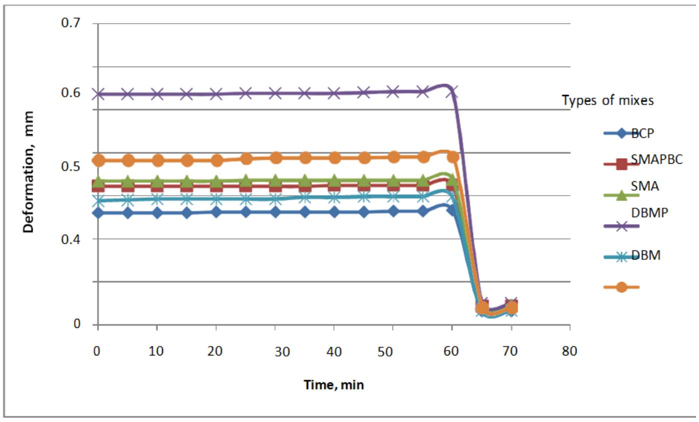

Figure 5.5: Deformation Values at 40 °C for SMA, BC, and DBM

VI. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

This study demonstrates that the addition of waste polyethylene, sourced from locally available OMFED milk packets, enhances the engineering properties of bituminous mixes (SMA, DBM, and BC). Using the Marshall method, the optimum binder and polyethylene contents were determined. The incorporation of polyethylene improved Marshall Stability, reduced drain down, increased retained stability, and enhanced indirect tensile strength and moisture resistance. BC mixes with polyethylene consistently showed the best performance across various tests.

Overall, the use of waste polyethylene not only offers an effective way to recycle non-biodegradable plastic but also improves the durability and performance of pavement materials, making it a sustainable solution for road construction.

6.2 Future Scope

a) Many properties of SMA, BC and DBM mixes such as Marshall Properties, drain down characteristics, static tensile strength, and static creep characteristics have been studied in this investigation by using only VG 30 penetration grade bitumen and polyethylene. However, some of the properties such as fatigue properties, resistance to rutting, dynamic indirect tensile strength characteristics and dynamic creep behavior needed to be investigated.

b) In present study polyethylene is added to them mix in dry mixing process. Polyethylene can also be used for bitumen modification by wet mixing process and comparisons made.

c) Microstructure of modified bituminous mixture should be observed by using appropriate technique to ascertain the degree of homogeneity.

d) Combination of paving mixes formed with other types of plastic wastes which are largely available, wastes to replace conventional fine aggregates and filler an different types of binders including modified binders, should be tried to explore enough scope of finding suitable materials for paving mixes in the event of present demanding situations.

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