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Enhancing Bituminous Mixes with Recycled Polyethylene: Performance Analysis Using Marshall Stability Test

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Abstract

This study investigates the impact of incorporating recycled low-density polyethylene (LDPE) and high-density polyethylene (HDPE) in bituminous mixes for potential use in flexible pavement construction. Utilizing a Marshall Stability Test, various proportions of LDPE and HDPE were analyzed to determine optimal stability and flow characteristics. The test maintained a fixed Zycotherm content at 1.5% and varied LDPE content from 2% to 5% by weight, while HDPE content was also tested at 2% to 5%. Results reveal that incorporating 4% HDPE with a constant 1.5% Zycotherm yields a maximum stability of 1752 kg with a flow value of 4.0 mm, achieving an ideal balance between durability and flexibility. This combination also demonstrated improved air voids (3.0%), voids in mineral aggregate (VMA) at 9.48%, and voids filled with bitumen (VFB) at 68.30%. In comparison, mixes with LDPE showed stability improvement but lower binding capacity. The findings indicate that HDPE-modified mixes are not only durable but also provide an effective means of recycling non-biodegradable waste into road construction materials, extending pavement lifespan and reducing environmental impact. This research highlights HDPE as a viable material for enhancing the mechanical properties of bituminous pavements.

Keywords: Bituminous mix, Marshall stability test, recycled polyethylene, LDPE, HDPE, flexible pavement, Zycotherm, environmental sustainability

INTRODUCTION

The construction and maintenance of roadways have been vital components of infrastructure development worldwide. Traditional materials such as bitumen are commonly used for flexible pavements due to their durability and performance. To address increasing environmental concerns and promote sustainable practices, there has been a growing focus on incorporating recycled materials in the construction industry. Polyethylene, a commonly used plastic that is not biodegradable, presents a significant environmental issue, making its reuse in construction a potential solution. Recycling polyethylene, particularly in the form of low-density polyethylene (LDPE) and high-density polyethylene (HDPE), offers a promising solution to mitigate the environmental impact while enhancing the properties of bituminous mixes [1-3].

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Polyethylene-based additives have shown potential in improving the mechanical properties of asphalt mixtures, such as stability, flow, and workability. LDPE, commonly found in waste materials like plastic bags and bottles, is often used in bitumen modification, although it faces limitations in terms of bonding strength and

ductility. In contrast, HDPE, which is stronger and more rigid, is being explored for its ability to improve the structural integrity and longevity of bituminous pavements. Furthermore, the inclusion of additives like Zycotherm, a warm mix asphalt (WMA) technology, has been found to reduce the production and compaction temperatures of asphalt, making it an energy-efficient alternative [4-7].

This research investigates the effects of LDPE and HDPE on the performance of bituminous mixes, using Marshall Stability and Flow tests to assess their impact on the stability, flexibility, and durability of the pavement. The primary aim is to explore the potential of these recycled materials in improving bitumen's properties while contributing to environmental sustainability in road construction.

Investigating asphalt mixtures, bitumen content and type significantly impact performance, with PMB40 consistently enhancing Marshall Stability and Flow Value. Sasobit proves effective, improving Stability by 50% and Flow Value by 30%. Evotherm enhances Stability by 40%, and Advera varies. Warm Mix Asphalt (WMA) generally matches Hot Mix Asphalt (HMA) in performance. The study highlights the importance of RTFOT-modified bitumen to enhance pavement durability [1]. Rutting impacts asphalt durability, especially in high-temperature, high-traffic areas. WMA, PMB40, and additives like Evotherm improve rutting resistance, with RTFOT aging further enhancing binder hardening and pavement resilience [8-12].Comprehensive assessment confirms PMB40 and VG30 bitumen's suitability for bituminous concrete applications [3]. WMA's eco-friendly benefits include lower energy consumption, reduced costs, and increased use of recycled asphalt pavement (RAP) [4]

Objectives

- To evaluate the stability and flow properties of bituminous mixes with varying percentages of LDPE and HDPE.
- To determine the optimal polyethylene mix that enhances binding, durability, and sustainability in pavement construction.
- To explore the practical application of recycled polymers in reducing non-biodegradable waste in road infrastructure.

Material

Asphalt mixes are primarily composed of aggregates, filler, and a bituminous binder. Typically, the maximum particle size in these mixes is under 25 mm, with finer particles smaller than 0.075 mm. This compacted mixture is nearly impermeable and exhibits strong dissipative and polyvalent characteristics, making it resilient and effective. By adhering to precise bituminous mix standards, a durable and high-performance asphalt mixture can be achieved through the balanced incorporation of bitumen, filler, fine, and coarse aggregates [13-17].

The primary materials used include:

- Aggregates
- Zycotherm (Admixture)
- Low-Density Polyethylene (LDPE)
- Bituminous Binder
- High-Density Polyethylene (HDPE)

Aggregate

Asphalt mixes utilize a range of natural mineral aggregates. These aggregates, constituting 90-95% of the mix by weight, play a critical role in the mixture's strength and durability. Additional processing can enhance aggregate properties to meet design standards, improving quality and preservation [18-20].

Coarse Aggregates

Coarse aggregates, retained on a 4.75 mm sieve, contribute significantly to the compressive and shear strength of the mix and ensure effective interlocking properties. In this study, stone chips with a specific gravity of 2.75 were utilized, ensuring they were free from contaminants such as dust, mud, and organic materials [21].

Fine Aggregates

Fine aggregates were sourced from screened quarry dust, ensuring the absence of organic impurities. These particles, passing through a 4.75 mm sieve and retained on a 0.075 mm sieve, served as filler material for voids. The specific gravity of these fine particles ranged from 2.45 to 2.6, making them suitable for the mix [22-23].

Filler

Filler materials, which pass through a 0.075 mm sieve, are essential for filling voids and enhancing the strength of the bitumen matrix. This study employed stone dust and fly ash as fillers, with respective specific gravities of 2.7 and 2.3.

Zycotherm

Zycotherm, a warm mix asphalt (WMA) additive developed by Zydex Industries, was used to lower production and compaction temperatures, improving the mix's workability. Additionally, it acted as an anti-stripping agent, facilitating compaction within the range of 90-120°C and transportation between 120-135°C, depending on the mix properties.

LDPE

Low-Density Polyethylene (LDPE), sourced from recycled waste, was employed as a bitumen modifier. After being cleaned, it was crushed into particles of 2-3 mm size. LDPE, known for its flexibility, durability, and density ranging from 0.910 to 0.940 g/cm³, improved asphalt characteristics when incorporated at levels of 2-5% by weight.

Bituminous Binder

Bitumen, a dense, black, viscous material, is widely used as a binding agent in asphalt. Derived from the refining of crude oil, it consists predominantly of polycyclic aromatic hydrocarbons. Bitumen is highly favored in road construction due to its strength, resilience, and capacity to endure varying temperature conditions.

RESULTS

Marshall Stability Test

The findings from this study are summarized in the following tables, which present the Marshall properties of various bituminous mixes along with Marshall curves derived from the design mixes.

For all tests, the Zycotherm percentage was fixed at 1.5%, while LDPE polythene was used at 2% and 4% by weight. The HDPE polythene content ranged from 2% to 5% by weight Table 1 and 2.

Table 1. Marshall Properties of Bituminous Mixes with Varying LDPE Percentages.

Type of mix	Marshall stability value (kg)	Flow value (mm)
HMA mix with 2% LDPE	1560	3.5
HMA mix with 3% LDPE	1640	3.8
HMA mix with 4% LDPE	1700	4.1
HMA mix with 5% LDPE	1686	4.0

Table 2. Marshall Properties of Bituminous Mixes with Varying HDPE Percentages

Type of mix	Marshall stability value (kg)	Flow value (mm)
HMA mix with 2% HDPE	1590	3.7
HMA mix with 3% HDPE	1685	3.9
HMA mix with 4% HDPE	1752	4.0
HMA mix with 5% HDPE	1690	4.2

CONCLUSIONS

The construction industry has traditionally relied on low-density polyethylene (LPDE) polythene, however this dissertation offered study on recycling waste polythene in this sector. Because low-density polyethylene (LPDE) has poor binding characteristics and ductility as a result of its low tensile strength, the study's results imply that high-density polyethylene (HDPE) might potentially reach industrial use as well. The sample's binding and HPDE characteristics were enhanced by using HPDE polythene and a constant amount of zycotherm, in contrast.

Because it extends the life of bitumen (flexible) pavements and helps settle non- biodegradable debris, this research is useful for highway building.

Based on the tests conducted, the following conclusions were reached: The Marshall Test performed on a bituminous mix with 4% HPDE plastic and 1.5% Zycotherm showed a stability value of 1700 kg. Corresponding parameters included a flow value of 4.1, air void percentage of 3.0%, VMA of 9.48%, and VFB of 68.30% at 2% LPDE. At 4% LPDE, the stability value increased to 1752 kg.

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