

Increasing Road Durability by Combining Polymer Waste in HMA.

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Abstract

The escalating traffic volume on city roads and inter-state highways necessitates the development of robust and sustainable road infrastructure. This experimental study explores the potential of incorporating polymer non-biodegradable waste, such as Low-Density Polyethylene (LDPE) and Crumb Rubber (CR), into bitumen to create more durable and environmentally friendly road materials. LDPE and C.R could also be called waste polymers as they are a waste end product.

A blend, termed Eco Mix, was formulated by combining bitumen with waste polymers like LDPE and CR in varying proportions (3%-9%). Marshall testing was conducted to evaluate the volumetric properties, stability, and flow characteristics of the Eco Mix-modified bitumen. Three different Eco Mix formulations (1:1, 1:2, and 1:3 ratios of bitumen to recycled waste) were prepared and substituted for bitumen in varying percentages. The results demonstrated that replacing 7% of bitumen with Eco Mix 3 (1.75% LDPE and 2.25% CR) led to the most significant improvement in engineering properties. This formulation exhibited enhanced volumetric properties, stability, and flow characteristics compared to the control mix and other Eco Mix formulations.

These findings suggest that by optimizing the blend composition and replacement ratio, it is possible to achieve improved road performance without compromising durability or environmental sustainability. Incorporating recycled materials into road construction can be a viable and effective solution to address both environmental concerns and the growing demand for resilient infrastructure.

Keywords: Low-Density Polyethylene (LDPE), Crumb Rubber, Sustainable Road Construction, Bitumen Modification, Plastic Waste Utilization, Environmental-Friendly Roads, Non-Biodegradable Waste.

1 Introduction

The burgeoning global waste crisis poses a severe environmental threat. As landfills reach capacity and concerns over environmental pollution intensify, researchers and industries are seeking innovative solutions to reduce the impact of non-biodegradable waste, such as plastic and rubber. One promising approach is to incorporate these waste materials into road construction materials, creating more sustainable and durable infrastructure.

This research explores the potential of using Low-Density Polyethylene (LDPE) and Crumb Rubber (CR) as modifiers for bitumen in Hot Mix Asphalt (HMA). Previous studies have demonstrated the feasibility of incorporating waste polymers into

HMA, but further investigation is needed to optimize their use and understand their long-term performance. By harnessing these recycled materials and waste polymers we can significantly reduce the environmental footprint of road construction.

Eco Mix 1, Eco Mix 2 and Eco Mix 3 are generally called Eco Mix.

This research aims to explore the engineering feasibility of using a blend of Low-Density Polyethylene (LDPE) and Crumb Rubber (CR) as a modifier for bitumen in HMA concrete generally called **Eco Mix**. The table below gives Eco Mix Composition.

Table 1: Eco Mix Composition

Eco Mix 1	LDPE and C.R were mixed Mechanically in the ratio of 1:1 called Eco Mix 1
Eco Mix 2	LDPE and C.R were mixed Mechanically in the ratio of 1:2 called Eco Mix 2
Eco Mix 3	LDPE and C.R were mixed Mechanically in the ratio of 1:3 called Eco Mix 3

When waste polymers like LDPE and C.R are mixed mechanically in the ratio of 1:3 it is termed as Eco Mix 3. By evaluating the compatibility and performance of Eco Mix 3 in Hot Mix Asphalt (HMA), this study aims to contribute to the development of more sustainable and cost-effective road construction practices. The objective of this experiment is to determine the optimal ratio of Eco Mix 3.

Asphalt is susceptible to deterioration over time due to a range of environmental and mechanical factors. Asphalt pavements can degrade due to temperature fluctuations, exposure to chemicals, and heavy traffic loads. However, treated asphalt offers

significant advantages in mitigating these issues. By incorporating additives or modifiers into asphalt, it is possible to reduce cracking, enhance fatigue and rutting resistance, minimize maintenance costs, extend service life, and improve the overall driving experience. A durable asphalt pavement is constructed from a carefully blended mixture of mineral aggregates, filler, and a high-quality binder. This mixture is heated to a temperature between 120°C and 140°C and laid on the road while still hot. The optimal bitumen blend incorporates well-graded aggregates and mineral filler, resulting in a high-density Hot Mix Asphalt (HMA) concrete with exceptional load-bearing capacity.

Several factors can contribute to the deterioration of asphalt pavements: These Include.

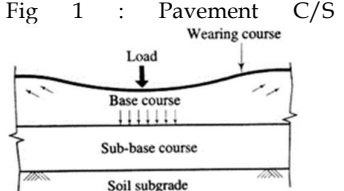
Stripping	Caused by separation of Asphalt Binder by aggregate thereby reducing pavement thickness and strength.	 Fig 1 : Pavement C/S
Poor Construction	Inadequate Compaction and substandard workmanship.	
Loss of pavement load-supporting characteristics	Loss of pavement load-supporting characteristics	
Increased Loading	Heavy load plying more than designed capacity.	

Fig 2: Asphalt Institute - Types of failures/distress.

				
Alligator Cracking	Block Cracking	Edge Cracking	Longitudinal Cracking	Transverse Cracking
				
Slippage Cracking	Reflective Cracking	Corrugation & Shoving	Rutting.	Potholes.

1.1 Review of Literature

Researchers have explored the integration of non-biodegradable polymers into asphalt in various blending methods and proportions to optimize modifier performance. Literature reviews consistently indicate that incorporating different percentages of ground plastic waste and crumb rubber granules into asphalt can enhance its strength, stiffness, and overall durability, leading to improved pavement performance and longevity.

Alemu et al. (2023) found that integrating plastic and crumb rubber into asphalt improved its stability, stiffness, and indirect tensile strength, reducing rutting.

Cardoso et al. (2023) reviewed studies using waste plastic and concluded that incorporating PET or HDPE can enhance asphalt's fatigue resistance and reduce rutting.

Gao et al. (2023) studied a polyurethane/waste rubber powder composite for asphalt. They observed that a 1:1 ratio of polyurethane to waste

rubber powder improved the asphalt's rutting resistance and water damage resistance.

Mohan et al. (2023) simulated the use of recycled plastic and crumb rubber in bitumen. They found that adding 4% of each material improved the binder's shear strength, ductility, and viscoelastic properties.

Ranganathan et al. (2023) studied the use of HDPE and crumb rubber in bitumen. They observed that adding 8% HDPE to the bitumen increased its Marshall Stability, improving rutting resistance and load-carrying capacity.

Paunikar et al. (2022) experimented with plastic-coated aggregates in flexible pavements. They found that this method can strengthen the bond between materials, improving road durability and reducing maintenance costs.

Singh & Chauhan (2021) studied the use of plastic and rubber waste in bitumen. They partially

replaced bitumen with 3-11% plastic and 4-20% rubber and observed that this improved the pavement's engineering properties and sustainability.

1.2 Importance of Study.

1. Sustainable Waste Utilization: This research aims to develop practical applications for low-cost modified admixtures derived from recycled materials, addressing environmental concerns related to waste disposal.

2. Enhanced Road Performance: Incorporating readily available modifiers into bitumen can improve the functionality and durability of asphalt roadways.

3. Cost-Effective Solutions: Utilizing modified admixtures can extend the lifespan of roads, resulting in significant savings on maintenance costs and providing long-term financial benefits.

1.3.1 Materials Used

Table 3 Material Properties of Bitumen

Properties	Results: Bitumen
Specific gravity	1.018
Penetration	42mm
Softening Point	52.70°C
Flash Point	255°C

1. Bitumen.(VG40).
2. Coarse Aggregate.
3. Fine Aggregate.
4. Dust.
5. Low Density Polyethylene (LDPE).
6. Crumb Rubber (C R).

1.4.2 Bitumen.

In this experiment, we incorporated VG 40 bitumen into the Hot Mix Asphalt (HMA) mixture. Bitumen offers several key benefits, including:

- **Surface wear resistance:** Helps prevent abrasion on the pavement surface.
- **Water resistance:** Reduces water intrusion and prevents damage.
- **Smoothness:** Ensures a smooth and even surface for vehicles.

- **Structural integrity:** Supports wheel loads and maintains the pavement's structural integrity.

1.4.3 Aggregates

- **Coarse Aggregate:** Particles larger than 13mm, conforming to MORTH specifications, were used.
- **Fine Aggregate:** Particles smaller than 4.75mm, meeting MORTH specifications, were used. Sieve sizes included 4.75mm and 2.36mm.
- **Dust:** Quarry stone particles finer than 2.36mm were used.
- These aggregates, along with a binding material such as bitumen, form the structural components of the pavement. To achieve optimal performance, aggregates must be strong, durable, tough, and hard.

Table 4: Aggregate Properties of HMA.

Properties	Coarse Aggregate	Fine Aggregate	Quarry Dust
Specific Gravity	2.907	2.876	2.747
Water Absorption	0.58%	2.876	1.63%

1.4.4 Low-Density Polyethylene (LDPE).

LDPE, a thermoplastic polymer derived from ethylene, is known for its strength and flexibility. It is widely used in products such as carry bags and packaging materials. LDPE can withstand temperatures as high as 80°C on a continuous basis. Given the highest measured temperature of 50°C to 55.°C LDPE is a suitable material for this experiment. We anticipate that adding LDPE to the pavement will increase its strength and durability.

1.4.5 Crumb Rubber.

Crumb rubber is a recycled material produced by shredding waste tires from trucks, automobiles, and other sources. It is essentially ground-up scrap rubber.

Table 5: Characteristics of LDPE & CR

Description	Characteristics of LDPE	Characteristics of CR
Maximum Temperature Hot.	176°F 80°C.	121°C
Maximum Temperature Cold.	-58°F -50°C.	NA
Density	0.91-0.94 gms per/cc	0.64-0.72 gms per/cc
Melting Point	105 -115 Degrees Celsius	170°C.
Flash Point	1 136 degree C (- 213 degree F)	320 degree C (608 degree F)
Fire Point	450 degree C (842 degree F)	-
Specific Gravity	2.44	1.15 ± 0.05

Fig 3: Materials required to produce Eco Mix



II. Research Methodology.

2.1 Mix Design and Preparation

Mix Design (Conventional): A traditional mix design approach was employed to formulate flexible pavement mixtures for both Dense Bituminous Macadam (DBM) and Base Course (BC). This involved blending coarse aggregate, fine aggregate, filler, and bitumen in specific proportions at the desired temperature during casting.

Modified Bitumen Preparation: A wet process was adopted to incorporate Low-Density Polyethylene (LDPE) and Crumb Rubber (CR) into the bitumen. This method is suitable for plastics with low melting points and has been shown to improve moisture resistance, rutting, and fatigue resistance in binder blends. In this process, LDPE and CR were heated to over 170°C and mechanically mixed in predetermined proportions.

2.2 Experimental Procedure

Stage 1 - Preparation of Conventional Mix: The Optimum Bitumen Content (OBC) of the conventional mix was determined to be 5.25%.

Stage 2 - Individual Modifier Replacement: LDPE and Crumb Rubber were individually replaced with bitumen to investigate their influence on Marshall Properties.

Stage 3 - Eco Mix 3 Preparation: Eco Mix 3 was replaced with bitumen in varying proportions, as per Table 9, to investigate its influence on Marshall Properties.

Stage 4 - Marshall Testing: The Marshall Properties, including stability and flow, were evaluated for each sample, and conclusions were drawn. This methodology enabled a comprehensive evaluation of the impact of LDPE and Crumb Rubber on the engineering characteristics of Hot Mix Asphalt (HMA) concrete.

Table 6 : Table to Compare Eco Mix 2 Properties Vs Other Parametres

Eco Mix 3	Vs	(a) Conventional HMA concrete with OBC percentage determined
Replaced with Bitumen	Vs	(b) LDPE individually replaced with Bitumen (@3%-9%).
(Varying between 3%-9%).	Vs	(c) Crumb Rubber individually replaced with Bitumen. (@3%-9%).

Table 7 : Bitumen Replaced with LDPE

Mix Type	Bitumen Content	LDPE %	CR %
Sample A	97.0%	3.00 %	0%
Sample A1	96.0 %	4.00 %	0%
Sample A2	95.0 %	5.00 %	0%
Sample A3	94.0 %	6.00 %	0%
Sample A4	93.0 %	7.00 %	0%
Sample A5	92.0 %	8.00 %	0%
Sample A6	91.0%	9.00 %	0%

Table 8 : Bitumen Replaced with CR

Mix Type	Bitumen Content	LDPE %	CR %
Sample B	97.0%	0.75 %	3.25%
Sample B1	96.0 %	1.00 %	3.00 %
Sample B2	95.0 %	1.25 %	2.75 %
Sample B3	94.0 %	1.50 %	2.50 %
Sample B4	93.0 %	1.75 %	2.25 %
Sample B5	92.0 %	2.00 %	2.00 %
Sample B6	91.0%	2.25%	1.75 %

Table 9 : Bitumen Replaced with Eco Mix1:3

Mix Type	Bitumen Content	LDPE%	CR%
Sample C	97.0%	3.00 %	0%
Sample C1	96.0 %	4.00 %	0%
Sample C2	95.0 %	5.00 %	0%
Sample C3	94.0 %	6.00 %	0%
Sample C4	93.0 %	7.00 %	0%
Sample C5	92.0 %	8.00 %	0%
Sample C6	91.0%	9.00 %	0%

- 1. Bitumen Blending:** Bitumen was blended with LDPE and Crumb Rubber in predetermined ratios as outlined in Table 5 to create experimental Marshall Mixes.
- 2. Marshall Testing:** Marshall Tests were conducted on all samples to evaluate volumetric properties, stability, and flow.
- 3. Material Testing:**

Bitumen: Volumetric tests, Marshall Stability, and flow were performed.

Table 10. OBC Conventional Mix

Mix Type	Bitumen Content	LDPE	CR
Conventional	5.25%	0%	0%

Aggregates: Impact value, Los Angeles abrasion test, flakiness, elongation, and specific gravity were determined.

2.3 Marshall Flow Properties of Mix: Volumetric Properties + Stability + Flow

Volumetric Properties of the mix: Volumetric properties that are of interest are these properties mentioned below and acceptable values/specification limits specified in Table 11 for HMA Concrete.

Table 11

Properties	Detailed Description.	Specification limits
Theoretical Specific Gravity (Gt):	Theoretical specific gravity Gt is the specific gravity without considering air voids, and is given by: (Gt):	
Bulk Specific Gravity (Gm):	The bulk specific gravity is the specific gravity considering air voids and is found out by: Gm	
Bitumen Volume (Vb):	The volume of bitumen Vb is the percent of volume of bitumen to the total volume and given by: Vb	
Air Voids (Vv):	Air voids Vv is the percent of air voids by volume in the specimen and is given by: Vv	3% to 5%
Voids in Mineral Aggregate(VMA):	VMA is the volume of voids in the aggregates, and is the sum of air voids and volume of bitumen, and is calculated from VMA Total voids in aggregates (air voids + bitumen).	12.5% Min
Voids Filled with Bitumen (VFB):	Voids filled with bitumen VFB is the voids in the mineral aggregate framework filled with the bitumen, and is calculated as: VFB	65% to 75%
Stability:	Maximum load before failure	9 KN Min
Flow:	Total deformation at maximum load	2mm to 4mm
Bitumen-Content Relationship: Marshall Quotient	As bitumen content increases, flow increases Until a peak point, then decreases.	2-5

2.3.1 Theoretical specific gravity of the mix (Gt) :

$$Gt = \frac{W1+W2+W3+Wb}{[(W1/G1)+(W2/G2)+(W3/G3)+(Wb/Gb)]}$$

2.3.2 Bulk specific gravity of mix (OR) Actual Specific Gravity (Gm) : $Gm = \frac{Wm}{(Wm - Ww)}$.

2.3.3 Air voids percent (Vv) : $Vv = [(Gt - Gm)100 / Gt]$

2.3.4 Percent volume of bitumen (Vb):

$$Vb = [(Wb / Gb) / (W1 + W2 + W3 + Wb) / Gm]$$

2.3.5 Voids in mineral aggregate (VMA):

$$VMA = Vv + Vb$$

2.3.6 Voids filled with bitumen (VFB) :

$$VFB = (Vb \times 100 / VMA)$$

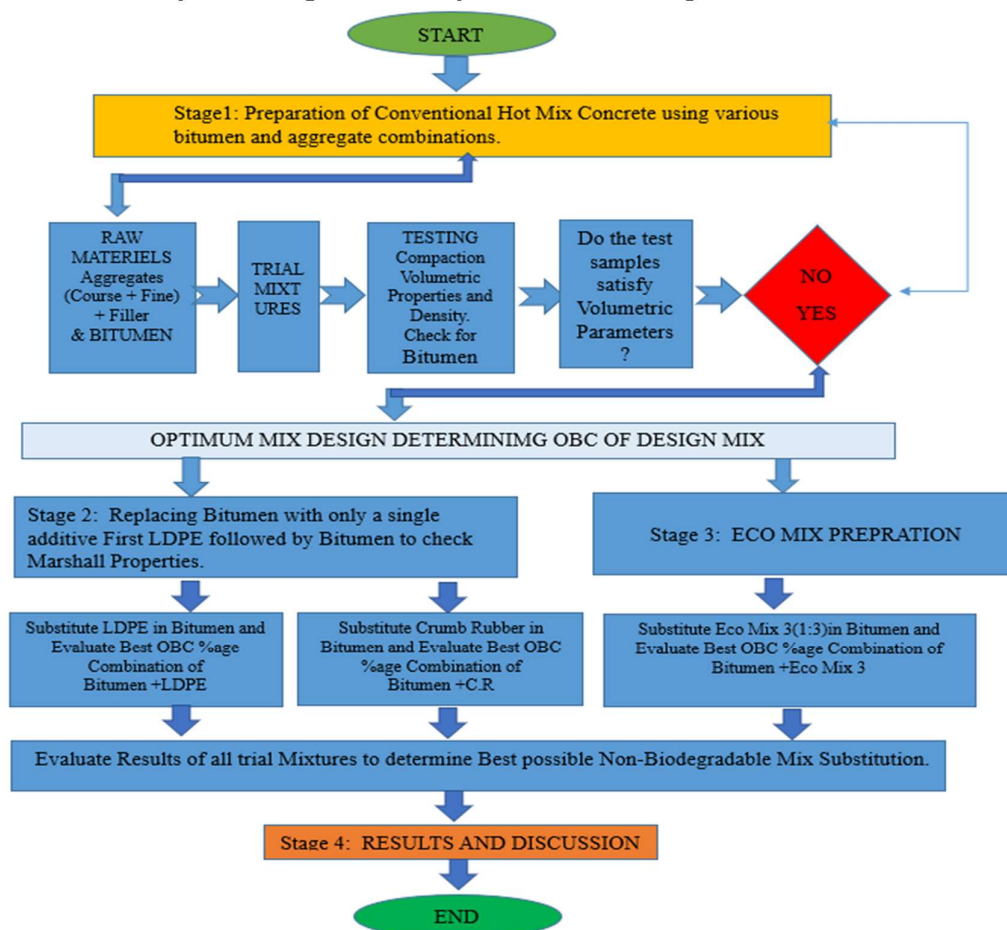
2.3.7. Stability - Bitumen content relationship: Stability is the maximum load required to produce failure of the specimen when load is applied at constant rate 50 mm / min.

2.3.8. Flow – Bitumen content relationship. Flow is the entire amount of deformation that happens at maximum load. Flow data for various bitumen contents demonstrate that as the flow of asphalt mix increases, so does the bitumen content, until it reaches its optimum volume of bitumen at a specific point.

2.4 .Flowchart

The flowchart below outlines the process of developing sustainable road construction materials From recycled polymer waste. By utilizing low-cost modified admixtures derived from these materials, the process addresses environmental concerns. Overall, the flowchart presents a systematic approach to creating sustainable road construction materials from recovered waste. It highlights the importance of carefully selecting, testing, and evaluating materials to ensure the quality and functionality of the final product.

FIG 4: Flow Chart Design Mix Formulation and Evaluation.
Laboratory Mix Design: Laboratory Test Results shall provide accurate results.



III. Results from the Experiments.

The Marshall Mix design for the standard Hot Mix Asphalt (HMA) mixture yielded an Optimum Bitumen Content (OBC) of 5.25%, corresponding to a compressive stability of 14.16 KN. Analysis of the

Marshall Mix design graph revealed a general trend of increasing Marshall Stability with rising bitumen concentration up to a certain point, followed by a decline.

3.1 Volumetric Analysis with Stability and Flow results to determine OBC of Conventional Mix.

Table 12. Tests on Aggregates

No	Experiments	Results Obtained	Acceptable Range
1	Impact Value (%)	25	10-20(Strong) 20-30(Good)
2	Los-Angeles Abrasion Test (%)	26	<30%
3	Flakiness (%)	10.3	<35%
4	Elongation (%)	33.60	<35%
5	Specific Gravity	2.6	2.5-3

Table 13. Tests on Bitumen

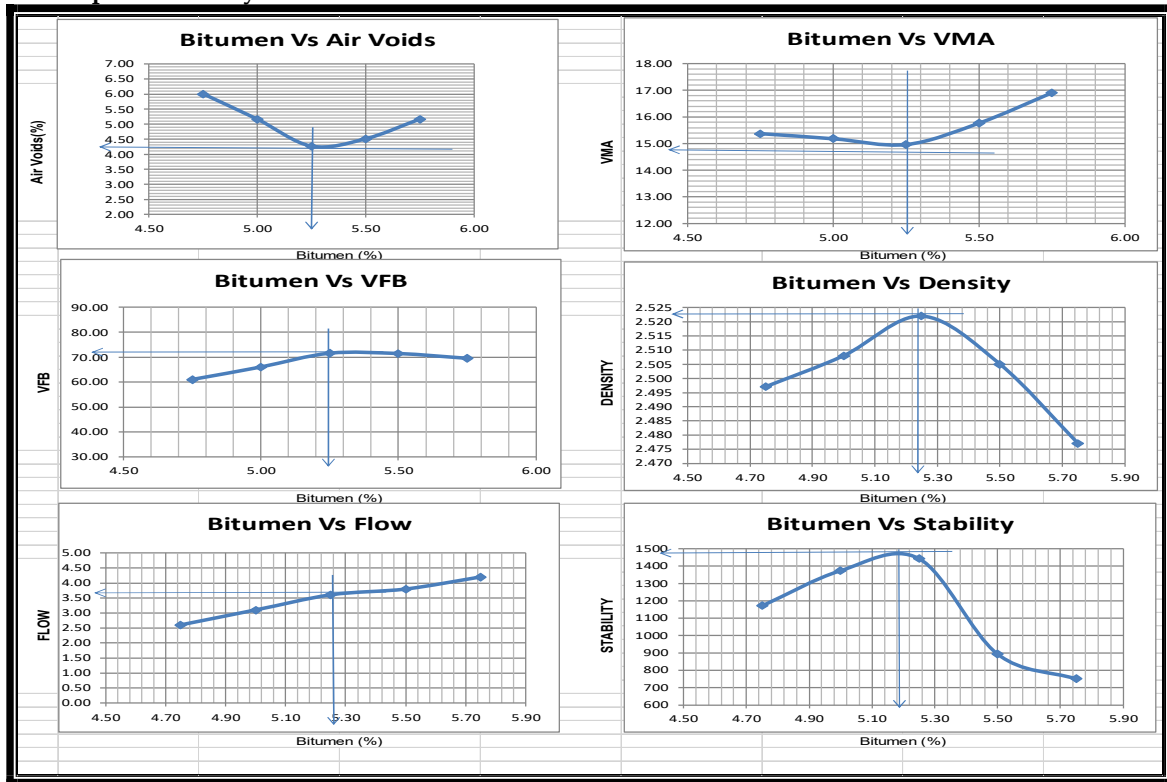
No	Tests	Bitumen Values
1	Specific Gravity	1.018
2	Penetration	42mm
3	Softening Point	52.70°C
4	Flash Point	255°C
5	Water Absorption	N.A

3.1.1 Results: Volumetric and Marshall Tests.

Table 14: Volumetric Analysis with Stability and Flow results to determine OBC of Conventional Mix.

No	% of bitumen /Total wt of Mix	Bulk Density (g/cc) Gb	Gmm (g/cc) Max Sp.Gr of Mix	VIM % Limits (3%-5%)	VMA% Limits (12.5% Min)	VFB % Limits (65% - 75%)	Stability (kg)	Stability (KN) Min Req'd 9KN	Flow (mm) (2-4)
1	4.75 %	2.497	2.656	6.00	15.37	60.99	1172	11.49	2.6
2	5.00 %	2.508	2.645	5.16	15.19	66.04	1374	13.47	3.1
3	5.25 %	2.522	2.634	4.26	14.97	71.52	1444	14.16	3.6
4	5.50 %	2.505	2.623	4.51	15.77	71.41	895	8.77	3.8
5	5.75 %	2.477	2.612	5.16	16.91	69.49	751	7.36	4.2

FIG 5: Graph of Stability and Flow values of Conventional Mix to determine OBC @5.25%.



Results: The Optimum Bitumen Content (OBC) for Conventional Mix HMA Concrete was determined to be 5.25%. This optimal bitumen content exhibited

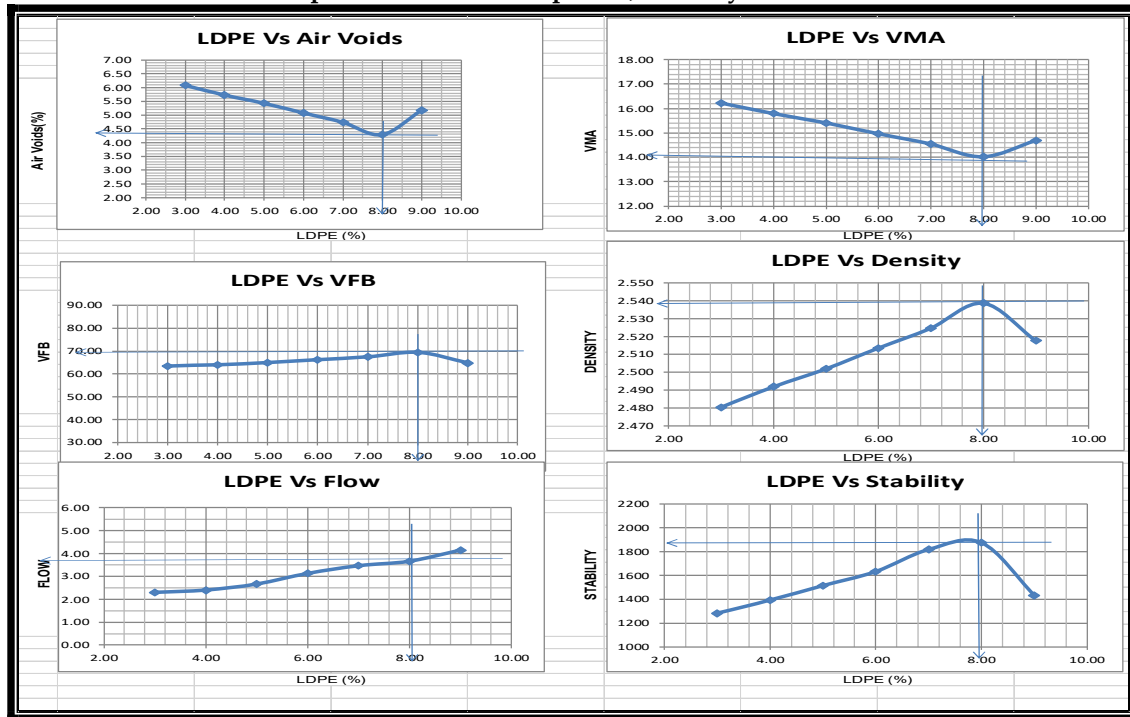
a stability factor of 14.16 KN and a flow rate of 3.6 mm. The detailed results are presented in Table 14 and Figure 5.

3.2 Volumetric & Marshall values for determining best LDPE % to substitute in bitumen.

Table 15: Volumetric, Stability and Flow Analysis Marshall Mix Design using LDPE.

No	% of bitumen by Total wt of Mix	Bulk Density (g/cc) Gb	Gmm (g/cc) Max Sp.Gr of Mixture	VIM (%) Limits (3%-5%)	VMA (%) Limits (12.5% Min)	VFB (%) Limits (65% - 75%)	Stability (kg)	Stability (KN) Min Req'd KN	Flow (mm)
1	3.00 %	2.507	2.641	5.07	15.33	66.93	1281	12.56	2.3
2	4.00 %	2.501	2.643	5.37	15.47	65.36	1392	13.65	2.4
3	5.00 %	2.502	2.646	5.43	15.41	64.91	1515	14.85	2.7
4	6.00 %	2.508	2.648	5.27	15.14	65.35	1632	16.00	3.1
5	7.00 %	2.525	2.650	4.74	14.54	67.42	1817	17.82	3.5
6	8.00 %	2.539	2.653	4.29	14.02	69.43	1874	18.37	3.8
7	9.00 %	2.518	2.655	5.17	14.68	64.77	1430	14.02	4.2

FIG 6: Graph of Volumetric Properties, Stability and Flow of LDPE.



3.2.1 Results: Volumetric and Marshall Tests

The optimal percentage of Low-Density Polyethylene (LDPE) to substitute in bitumen was determined to be 8.00%. This Optimum Bitumen

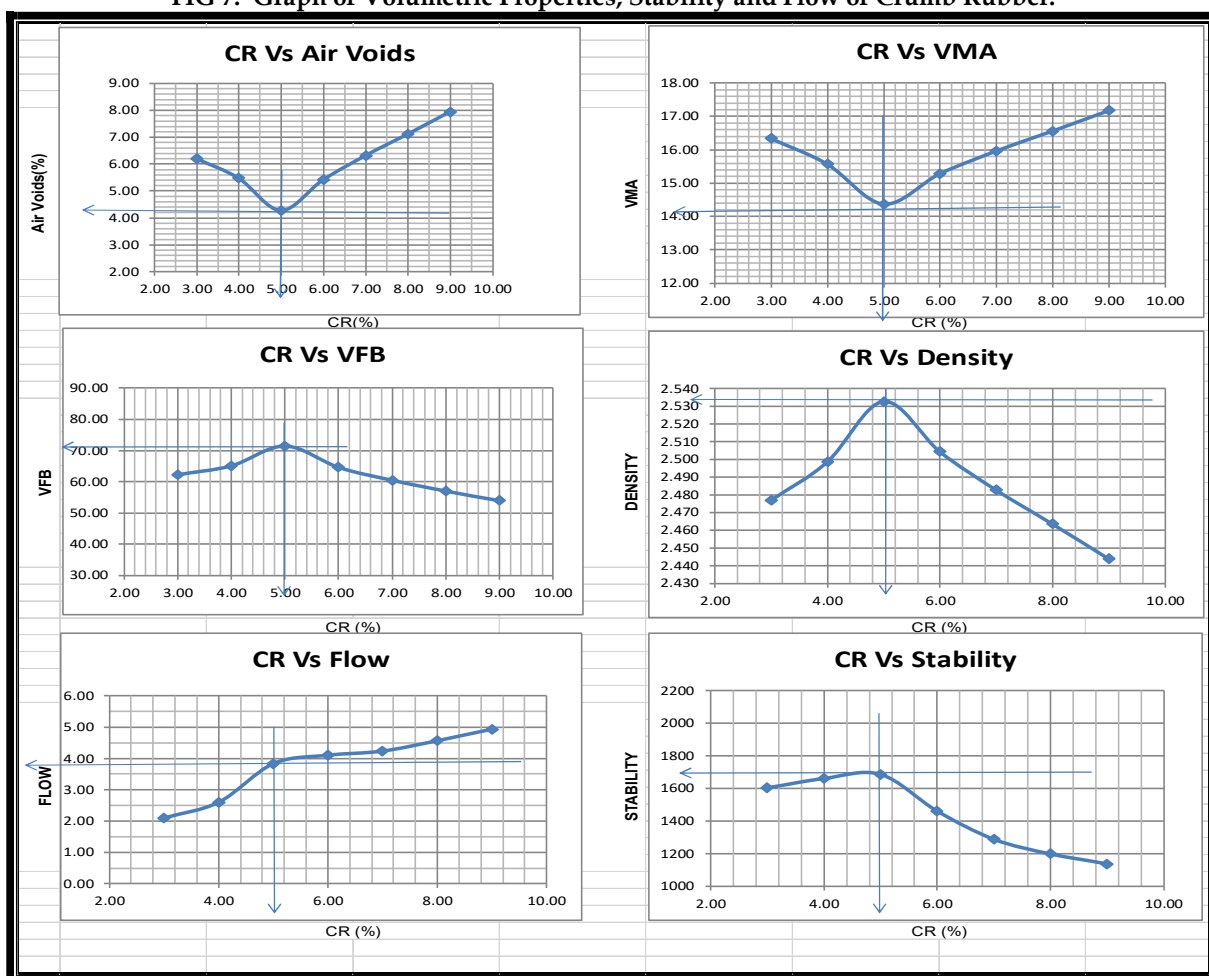
Content (OBC) for LDPE Mix exhibited a stability factor of 18.37 KN and a flow rate of 3.8 mm. The detailed results are presented in Table 15 and Figure 6.

3.3 Volumetric & Marshall Values to determine best crumb rubber % to substitute in bitumen

Table 16: Volumetric, Stability and Flow Analysis Marshall Mix Design using Crumb Rubber.

No	% of bitumen by Total wt of Mix	Bulk Density (g/cc) G _b	G _{mm} (g/cc) Max Sp.Gr of Mixture	VIM (%) Limits (3%- 5%)	VMA (%) Limits (12.5% Min)	VFB (%) Limits (65% - 75%)	Stability (kg)	Stability (KN) Min Reqd 9KN	Flow (mm) (2-4) mm
1	3.00 %	2.477	2.641	6.21	16.34	62.28	1603	15.72	2.1
2	4.00 %	2.498	2.643	5.48	15.57	65.07	1660	16.27	2.6
3	5.00 %	2.533	2.646	4.27	14.37	71.43	1687	16.54	3.8
4	6.00 %	2.504	2.648	5.42	15.27	64.62	1460	14.31	4.1
5	7.00 %	2.483	2.650	6.32	15.96	60.46	1288	12.63	4.2
6	8.00 %	2.464	2.653	7.13	16.56	57.02	1197	11.73	4.6
7	9.00 %	2.444	2.655	7.95	17.18	53.99	1136	11.15	4.9

FIG 7: Graph of Volumetric Properties, Stability and Flow of Crumb Rubber.



3.3.1 Results: Volumetric and Marshall Tests

The optimal percentage of Crumb Rubber to substitute in bitumen was determined to be 5.00%. This Optimum Bitumen Content (OBC) for Crumb

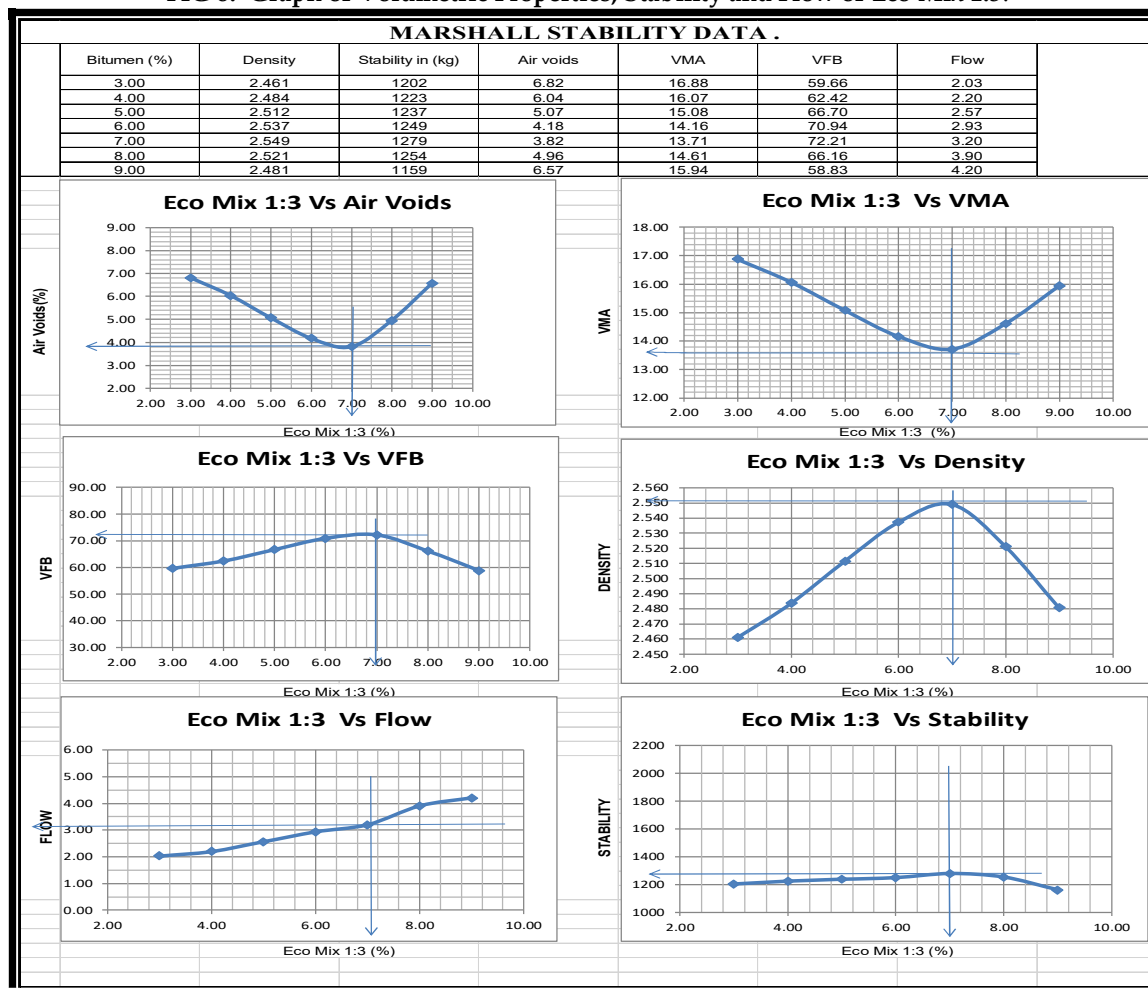
Rubber Mix exhibited a stability factor of 16.54 KN and a flow rate of 3.8 mm. The detailed results are presented in Table 16 and Figure 7.

3.4 Volumetric and Marshall values for determining the best Eco Mix 3 % to substitute in bitumen

Table 17: Volumetric, Stability and Flow Analysis Marshall Mix Design using ECO MIX 1:3.

No	% of bitumen by Total wt of Mix	Bulk Density (g/cc) Gb	Gmm (g/cc) Max Sp.Gr of Mixture	VIM (%) Limits (3%-5%)	VMA (%) Limits (12.5% Min)	VFB (%) Limits (65% - 75%)	Stability (kg)	Stability (KN) Min Req'd 9KN	Flow (mm) (2-4) mm
1	3.00 %	2.461	2.641	6.82	16.88	59.66	1202	11.78	2.0
2	4.00 %	2.484	2.643	6.04	16.07	62.42	1223	11.99	2.2
3	5.00 %	2.512	2.646	5.07	15.08	66.70	1237	12.13	2.6
4	6.00 %	2.537	2.648	4.18	14.16	70.94	1249	12.24	2.9
5	7.00 %	2.549	2.650	3.82	13.71	72.21	1279	12.54	3.2
6	8.00 %	2.521	2.653	4.96	14.61	66.16	1254	12.29	3.9
7	9.00 %	2.481	2.655	6.57	15.94	58.83	1159	11.36	4.2

FIG 8: Graph of Volumetric Properties, Stability and Flow of Eco Mix 1:3.



3.4.1 Results: Volumetric & Marshall Tests

The optimal substitution rate of ECO-MIX 2 was determined to be 7.00%. This Optimum Bitumen Content (OBC) for Eco Mix 3 exhibited a stability

factor of 12.54 KN and a flow rate of 3.2 mm. The detailed results are presented in Table 17 and Figure 8.

3.5 Results Summary

LDPE Substitution: Replacing 8% of the bitumen with Low-Density Polyethylene (LDPE) resulted in a maximum observed stability of 18.37 KN, along with a flow rate of 3.8 mm. **Crumb Rubber Substitution:** Substituting 5% of bitumen with Crumb Rubber produced a maximum stability of 16.54 KN, also with a flow rate of 3.8 mm.

ECO Mix 3 Substitution: Incorporating 7% of Eco Mix 3 (a 1:3 ratio of LDPE and Crumb Rubber) yielded a maximum stability of 12.54 KN with a flow rate of 3.2 mm.

3.6 Cost Estimation and Savings

Road Construction in India

Roads in India are typically constructed with widths ranging from 3.0 meters to 4.0 meters. For a 1 km stretch of road with a width of 3.75 meters, approximately 21,300 kg of bitumen is required.

Cost Savings Using Eco Mix 3

By substituting 7% of the bitumen with Eco Mix 3 (a 1:3 ratio of Low-Density Polyethylene and Crumb Rubber), significant cost savings can be achieved. This reduction in bitumen usage can lead to substantial financial benefits for road construction projects.

Table 18: Cost of laying New Road: Considering Bitumen Component only.

Item	Description	Quantity	Rate	Amount(₹)
(i)	Qty of Bitumen used in 1km Conventional-road @3.75m Width	2300 Kgs	55/Kg	1171500

Table 19: Quantity of Bitumen for Laying Eco Mix 3 Road

The Cost of Waste Plastics	₹11 / Kg.	The Cost of Waste Plastics	₹ 8 / Kg.
The Cost of Processing	₹ 5 / Kg.	The Cost of Processing	₹ 5 / Kg.
The Total cost of Waste Plastics	₹16 / Kg.	The Total cost of Waste Plastics	₹ 13 / Kg.

- | | |
|--|---|
| <p>a) Bitumen Requirement for Conventional Road = 21300 Kgs</p> <p>b) Replacement at 1:3 =7% i.e. 7% of 21300 = 1491 Kgs(i.e. 2.3% LDPE and 4.7% CR)</p> <p>c) LDPE Requirement @ 1:3= 1.75% of 21300 = 372.75 Kgs</p> | <p>d) CR Requirement @ 1:3= 2.25% of 21300= 1118.25 Kgs.</p> <p>e) Total Requirement of LDPE (c) +CR (d) = 1491 Kgs.</p> <p>f) Qty of Bitumen Required for New Road using 1:3 = 21300Kgs - 1491Kgs= 19809kgs.</p> |
|--|---|

Table 20: Cost of Bitumen for Laying Eco Mix 3 Road

Item	Description	QTY(Kgs)	Per/Kg	AMT (₹)
(ii)	Quantity of Bitumen in 1km Modified mix road @3.75m Width	19809	55	1089495
(iii)	Quantity of LDPE Consumed in Eco Mix 3 Road	372.75	16	5964
(iv)	Quantity of Crumb Rubber Consumed in Eco Mix 3 Road	1118.25	13	14537.25
(v)	Total Costing of asphalt mix For Modified Mix Road			1109996.25

- **Total Savings: ₹ 117,150 - ₹ 1,110,369 = ₹ 61,503.75**

Total Savings Using Eco Mix 3 = Item (i) - Item (v) = ₹ 1171500 - ₹ 1110369 = ₹ 61131.

- **Savings per KM: ₹ 61,503.75**

Savings Using Eco Mix 1:3 Over Conventional Mix = ₹ 61131 per KM

- **Percentage Savings per KM = 5.25%**

Percentage Savings per KM = (₹ 61503.75 ÷ ₹ 1171500) x 100 = 5.25%

Hence, using Eco Mix 3 in road construction can result in a 5.25% cost savings compared to conventional bitumen. This is primarily due to the reduced bitumen requirement and the inclusion of recycled materials.

IV Conclusion

Incorporating combined polymer waste into hot mix asphalt presents a promising opportunity for sustainable road construction. This strategy can contribute to a more environmentally friendly and sustainable future by reducing waste, conserving resources, and potentially enhancing pavement performance. However, careful evaluation of challenges, research, and development are essential to ensure the successful implementation of this technology.

Replacing bitumen with 8% Low-Density Polyethylene (LDPE) improves stability by 29.37%, making it particularly suitable for areas with high temperatures and tropical rainfall.

Substituting 5% of bitumen with Crumb Rubber increases stability by 16.08%, which is beneficial in high-traffic locations.

Replacing Bitumen with 7% Eco Mix 3 enhances stability by 5.67% compared to the minimum required stability of 9 KN under MORTH standards. This makes it particularly useful in areas with high traffic intensity and tropical rainfall.

The combined polymer waste of Eco Mix 3, with a 7% bitumen substitution, can be used to create an effective Job Mix Formula and is recommended for road repairs and laying due to its favourable engineering characteristics.

Polymer-modified solutions, such as Eco Mix 3, are well-suited for India's moderate to hot tropical climate. They can also help to mitigate the impact of heavy rains and extend the lifespan of roads. Further research and development are needed to address limitations and optimize the benefits of this innovative technology.

Also Eco Mix 3 which is a combined polymer waste offers an overall saving of 5.25% per kilometre and reduces environmental waste. This sustainable solution makes road construction more eco-friendly and cost-effective. The reduction in bitumen content can lead to significant savings in road laying expenses and a decrease in environmental waste. It is particularly effective in hot, rainy climates and high-traffic areas. Further research can optimize its use.

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