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Sustainable Road Construction By Incorporating Non-Biodegradable Waste In Hma: An Experimental Study

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The increasing demand for durable and sustainable roads has become a pressing issue due to rising traffic volumes and varying climatic conditions. The disposal of non-biodegradable waste from industrial sources poses a significant environmental challenge. This study explores the potential of utilizing recycled materials, such as discarded plastic and rubber, in road pavement construction to reduce environmental impact.

By incorporating a blend of Low-Density Polyethylene (LDPE) and Crumb Rubber (CR) into Hot Mix Asphalt (HMA) concrete, we investigated the feasibility of improving its engineering characteristics. The blend, termed **Eco** (Economic & Environment friendly) **Mix** was substituted for bitumen in varying proportions (3%-9%). Marshall testing was conducted to evaluate volumetric properties, stability, and flow.

This experiment was conducted using three different Eco Mix formulations (1, 2, and 3) which are three ratios of bitumen to recycled waste (1:1, 1:2, and 1:3). The results showed that replacing 7% of bitumen with Eco Mix 2, which contains 2.34% low-density polyethylene (LDPE) and 4.66% crumb rubber (CR), yielded the most promising performance in terms of improved engineering properties. This suggests that incorporating recycled materials into road construction can be a sustainable and effective solution that addresses both environmental concerns and the need for durable infrastructure.

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

I Introduction.

The increasing accumulation of solid waste poses a significant environmental challenge for countries worldwide. To mitigate this issue, researchers and industries are exploring innovative approaches to recycle or repurpose waste materials, reducing their environmental impact while adding value to products.

One promising avenue is the incorporation of waste polymers, such as discarded plastic and rubber, into road construction materials. These materials can potentially enhance the sustainability and performance of roads. Previous studies have investigated the use of waste polymers in Hot Mix Asphalt (HMA) concrete, focusing on their compatibility with bitumen and their influence on bitumen characteristics (Al-Hadidy et al., 2011; Navarro et al., 2009; Martin et al., 2006; González et al., 2008).While commercially available engineered polymers can be costly, waste plastic and rubber offer a more economical alternative. These materials have demonstrated potential applications in various fields, including road construction (Brovelia et al., 2015; Cuadri et al., 2013; Fuentes- Audén et al., 2008; Fang et al., 2012; González et al., 2016).

Asphalt is susceptible to degradation over time due to a combination of environmental and mechanical factors. Temperature fluctuations, exposure to chemicals, and heavy traffic loads can all contribute to the deterioration of asphalt pavements. However, modified asphalt offers several advantages in mitigating these challenges. By incorporating additives or modifiers into asphalt, it is possible to: 1. Reduce cracking, 2. Improve resistance to fatigue and rutting, 3, Reduce maintenance and increase service life & 4.Enhance drive quality.

This research aims to explore the 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 waste polymers will be mechanically mixed in a 1:2 ratio, creating a modified mix also termed "Eco Mix 2." for this experiment. By analysing the compatibility and performance of Eco Mix 2 in HMA, this study seeks to contribute to the development of more sustainable and cost-effective road construction practices. The objective of this experiment aims to identify the optimal ratio of Eco Mix 2 to be used in a Job mix formula and contribute to developing sustainable road construction practices

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

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

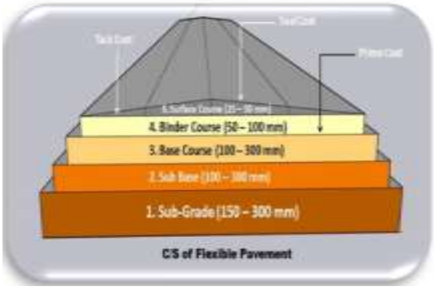


Fig1: C/S of Flexible Pavement

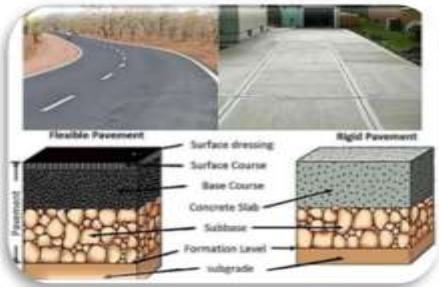
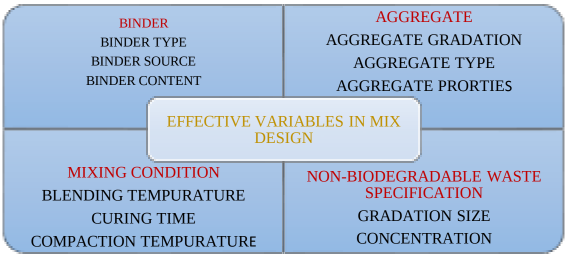


Fig 2: Flexible Pavement and Rigid Pavement Section

Fig 3: Preparation Of Marshall Mould

Fig 4 : Laying of Road using Modified Bitumen.

Fig 5: Effective Variables in Mix Design



A durable asphalt pavement is composed of mineral aggregates, filler, and a high-quality binder, carefully mixed in a hot mix facility and laid while hot. The optimal combination of bitumen, well-graded aggregates, and mineral filler results in a high-density HMA concrete with excellent load-carrying capacity.

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

- **Structural degradation:** Weakening of the pavement's foundation (base, subbase, or subgrade) due to factors like poor drainage, frost heave, or erosion.
- **Binder-aggregate separation:** Stripping, where the asphalt binder separates from the aggregate, compromising the pavement's strength and thickness.
- **Overloading:** Exceeding the pavement's design load capacity, leading to excessive stress and wear.
- **Inadequate design:** Insufficient structural capacity to support anticipated loads.
- **Construction deficiencies:** Poor workmanship, such as inadequate compaction, can contribute to early pavement failure.

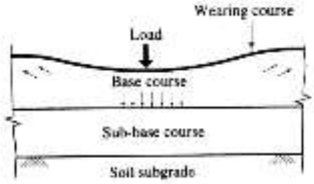


Fig 6 .Wearing Course

Fig 7: 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.

Numerous studies have explored the use of a combination of Low-Density Polyethylene (LDPE) and Crumb Rubber as modifiers for asphalt. Researchers have experimented with various blending methods and proportions to optimize their 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. These modifications can lead to improved pavement performance and longevity.

Alemu et al. (2023) studied using PET plastic and crumb rubber to modify asphalt. They found that combining these materials improved the asphalt's stability, stiffness, and indirect tensile strength, reducing rutting.

Cardoso et al. (2023) reviewed studies on using plastic waste in asphalt. They found that incorporating PET or HDPE can improve asphalt's fatigue resistance and reduce rutting.

Gao et al. (2023) studied a polyurethane/waste rubber powder composite for asphalt. They found 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 using 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 using HDPE and crumb rubber in bitumen. They found that adding 8% HDPE to the bitumen increased its Marshall Stability, improving rutting resistance and load-carrying capacity

Paunikar et al. (2022) explored using 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 using plastic and rubber waste in bitumen. They partially replaced bitumen with 3-11% plastic and 4-20% rubber and found that this improved the pavement's engineering properties and sustainability.

Hence the identified Research Gap - This research seeks to identify practical applications for low-cost modified admixtures derived from recycled materials. By repurposing waste products, this study aims to address environmental concerns related to waste disposal while providing innovative and sustainable solutions for various industries.

1.2 Importance of Study.

1. **Sustainable Waste Utilization:** This research aims to identify practical applications for low-cost modified admixtures derived from recycled materials, addressing environmental concerns related to waste disposal.
2. **Enhanced Road Performance:** By incorporating readily available modifiers into bitumen, this study explores the potential to improve the functionality and durability of asphalt roads.
3. **Cost-Effective Solutions:** The extended lifespan of roads achieved through the use of these modified admixtures can lead to significant reductions in maintenance costs and long-term financial savings.

1.2.1Materials Used.

a) Bitumen. (VG40).
b) Coarse Aggregate.
c) Fine Aggregate.
d) Dust.
e) Low Density Polyethylene (LDPE).
f) Crumb Rubber (C R).

Table 2 Material Properties of Bitumen

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

1.2.2 Bitumen.

For this experiment, we used VG 40 bitumen in the HMA mixture. Bitumen offers several desirable properties as below.

- Surface wear resistance: Protects the pavement surface from abrasion.
- Water infiltration reduction: Minimizes water penetration, preventing damage.

- Smooth finish: Provides a smooth and even surface for vehicles.
- Structural support: Supports wheel loads and contributes to the pavement's structural integrity.

1.2.3 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, when combined with a binding material like bitumen, form the structural components of the pavement. To ensure optimal performance, aggregates should exhibit high strength, durability, toughness, and hardness.

Table 3: 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%

1.3.4 Low-Density Polyethylene (LDPE).

LDPE, a thermoplastic polymer derived from ethylene, is known for its durability and flexibility. It is widely used in applications such as carry bags and packaging materials. LDPE can withstand temperatures up to 80°C continuously and 95°C for short periods. Given the maximum recorded temperature of 55.4°C in the study area, LDPE is a suitable choice for use in this experiment. By incorporating LDPE into the pavement, we anticipate improvements in both strength and durability.

1.3.5 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 4: 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 8: Materials required to produce Eco Mix

					
Plain Bitumen	**Coarse Aggregate**	**Fine Aggregate**	**LDPE Granules**	**Tyre C R Granules**	**Modified Bitu.men**

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 LDPE and Crumb Rubber 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 was heated to more than 170°C and Mixed mechanically in predetermined proportions.

2.2 Experimental Procedure.

1. **Stage 1-Preparation of Conventional Mix:** The Optimum Bitumen Content (OBC) of the conventional mix was determined to be 5.25%.
2. **Stage 2-Individual Modifier Replacement:** LDPE and Crumb Rubber were individually replaced with bitumen to study their effects on Marshall Properties.
3. **Stage 3-Eco Mix 2 Preparation:** The same procedure was repeated for Eco Mix 2, following the sampling plan outlined in Table 5.
4. **Stage 4-Marshall Testing:** The results of Marshall Properties, including stability and flow, were evaluated for each sample and the conclusions were reached.

This methodology allowed for a comprehensive assessment of the impact of LDPE and Crumb Rubber on the engineering characteristics of HMA concrete

Table 5 : Table to Compare Eco Mix 2 Properties Vs Other Parametres

Eco Mix 2 Replaced with Bitumen (Varying between 3%-9%).	Vs	**(a)** Conventional HMA concrete with OBC percentage determined
	Vs	**(b)** LDPE individually replaced with Bitumen (@3%-9%).
	Vs	**(c)** Crumb Rubber individually replaced with Bitumen. (@3%-9%).

Table 6. OBC Conventional Mix Design Bitumen %age

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

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%	3.00 %	0%
Sample B1	96.0 %	4.00 %	0%
Sample B2	95.0 %	5.00 %	0%
Sample B3	94.0 %	6.00 %	0%
Sample B4	93.0 %	7.00 %	0%
Sample B5	92.0 %	8.00 %	0%
Sample B6	91.0%	9.00 %	0%

Table 9 : Bitumen Replaced with Eco Mix1:2

Mix Type	Bitumen Content	LDPE %	CR %
Sample C	97.0%	1.50 %	1.50%
Sample C1	96.0 %	2.00 %	2.00 %
Sample C2	95.0 %	2.50 %	2.50 %
Sample C3	94.0 %	3.00 %	3.00 %
Sample C4	93.0 %	3.50 %	3.50 %
Sample C5	92.0 %	4.00 %	4.00 %
Sample C6	91.0%	4.50 %	4.50 %

2.2 Experimental Program:

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. **Experimental Sample Testing:**

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

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

The Marshall Mix design method is a common procedure used to evaluate the performance of asphalt concrete mixtures. It involves a series of laboratory tests to determine the optimal bitumen content and compaction level for a given mix design.

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

Optimum Mix Design: The goal of the Marshall mix design method is to find the combination of bitumen content and compaction level that results in a mixture with:

- **High stability:** To resist rutting and deformation.
- **Low flow:** To minimize permanent deformation.
- **Acceptable volumetric properties:** To ensure proper drainage and resistance to moisture damage.

Volumetric Properties of the mix: Volumetric properties that are of interest are these properties mentioned below and acceptable values specified in Table 10 for HMA Concrete.

1. **Theoretical Specific Gravity (Gt)**: Calculated without considering air voids.
2. **Bulk Specific Gravity (Gm)**: Calculated considering air voids.
3. **Air Voids (Vv)**: Percentage of air voids in the mix.
4. **Bitumen Volume (Vb):** Percentage of bitumen volume in the mix.
5. **Voids in Mineral Aggregate (VMA):** Total voids in aggregates (air voids + bitumen).
6. **Voids Filled with Bitumen (VFB):** Percentage of voids filled with bitumen.
7. **Stability:** Maximum load before failure.
8. **Flow:** Total deformation at maximum load.
9. **Bitumen-Content Relationship:** As bitumen content increases, flow increases Until a peak point, then decreases.

Table 10: Specification Limits

No	Description	Specification limits
1	Va (% Air voids) (%)	3 to 5 %
2	VMA (%)	12.5% Min
3	VFB (%)	65 to 75%
4	Stability (kg)	9 KN Min.
5	Flow (mm)	2 to 4mm
6	Marshal Quotient	2-5

2.3.1 Theoretical specific gravity of the mix (Gt) : Theoretical specific gravity Gt is the specific gravity without considering air voids, and is given by:

Gt= {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) : The bulk specific gravity is the specific gravity considering air voids and is found out by: **Gm={Wm/(Wm - Ww)}.**

2.3.3 Air voids percent (Vv) : Air voids Vv is the percent of air voids by volume in the specimen
and is given by: **Vv**= [(Gt-Gm)100/Gt] .

2.3.4 Percent volume of bitumen (Vb): The volume of bitumen Vb is the percent of volume of bitumen to the total volume and given by: **Vb**= [(Wb/Gb)/(W1+W2+W3+Wb)/Gm].

2.3.5 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**=Vv + Vb
2.3.6 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 = (Vb x100/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 (Jendia, 2000).

2.3.8. Flow – Bitumen content relationship. Flow is the total amount of deformation which occurs at maximum load (Jendia, 2000). Flow results for different bitumen contents show that as Flow of asphalt mix increases as the bitumen content increase till it reaches the peak at the max bitumen content at a certain point.

Table 11. Tests on Aggregates

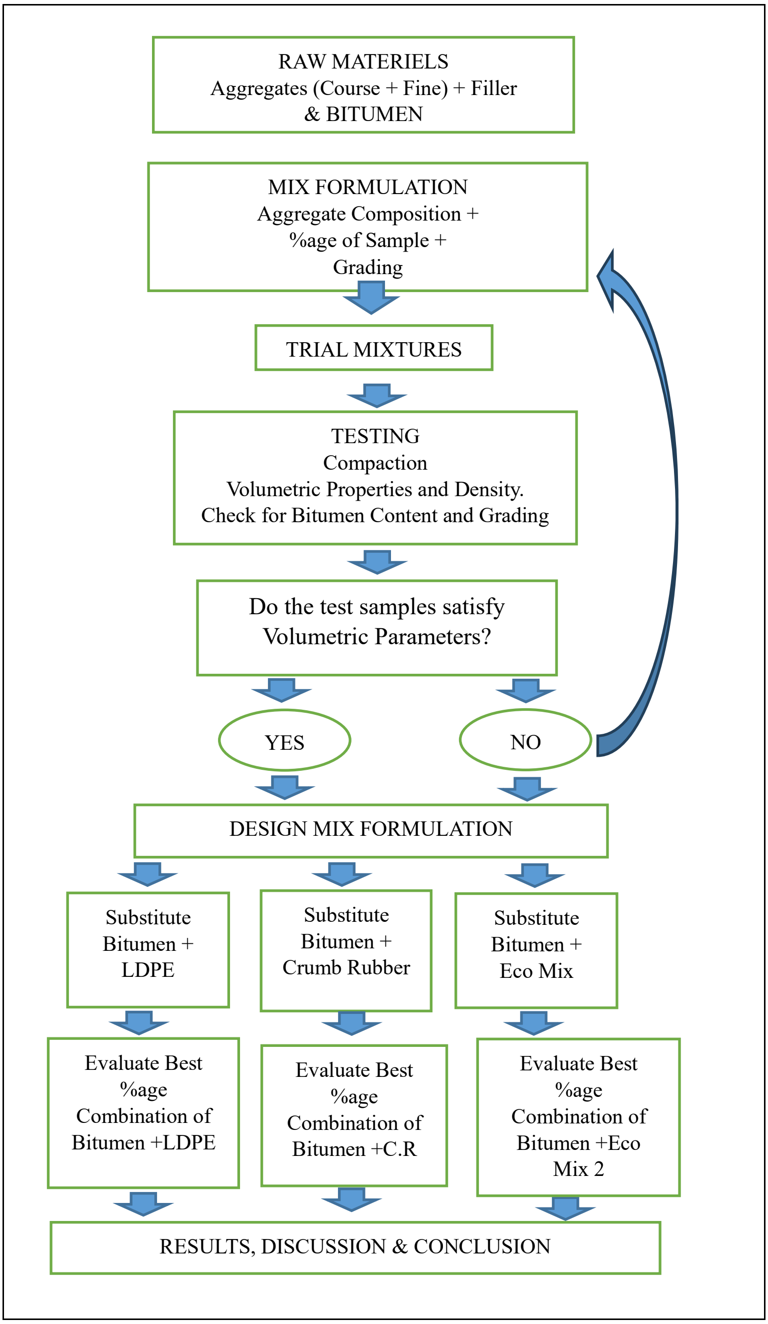
Table 12. Tests on Bitumen

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

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

The flowchart below outlines the process of designing sustainable road construction materials using recycled waste products. It focuses on using low-cost modified admixtures derived from these materials to address environmental concerns. Overall, the flowchart demonstrates the systematic approach to developing sustainable road construction materials using recycled waste products. It highlights the importance of careful material selection, testing, and evaluation in ensuring the quality and performance of the final product.

Fig 9: Flow Chart Design Mix Formulation and Evaluation.
Laboratory Mix Design: Laboratory Test Results shall provide accurate results.



III. Results from the Experiments.

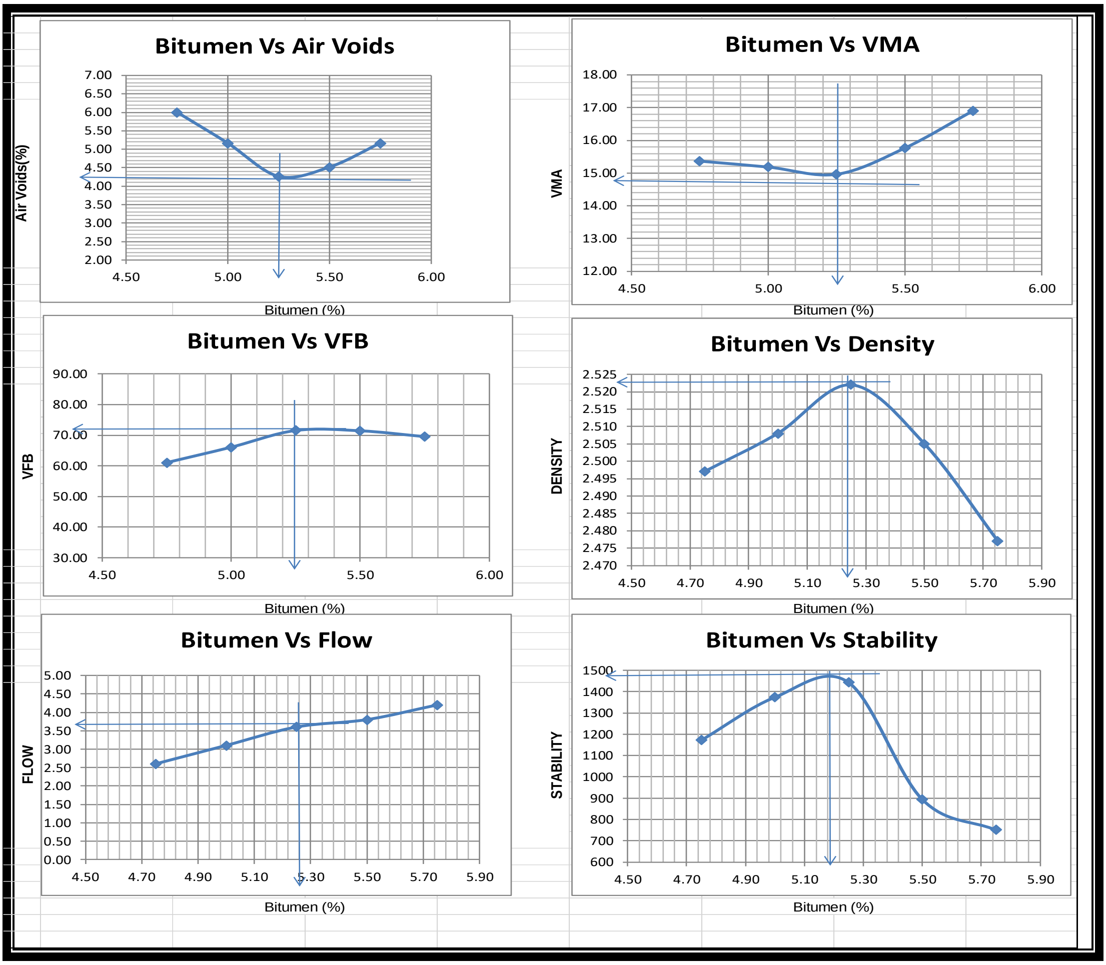
The experiment results demonstrated the potential of using recycled materials (LDPE and CR) in road construction. Incorporating Eco Mix 2 into HMA can improve its engineering characteristics while addressing environmental concerns. This approach offers a sustainable and effective solution for building durable road infrastructure. Suggests that recycled materials can enhance road durability and sustainability. Eco Mix 2 (1:2 ratio of bitumen to recycled waste): 7% replacement: Optimal substitution level.

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

Table 13: 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 Reqd 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 10: Graph of Stability and Flow values of Conventional Mix to determine OBC @5.25%.



3.1.1 Results: The Marshall Mix design for the conventional 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 increasing bitumen content up to a certain point, followed by a decrease.

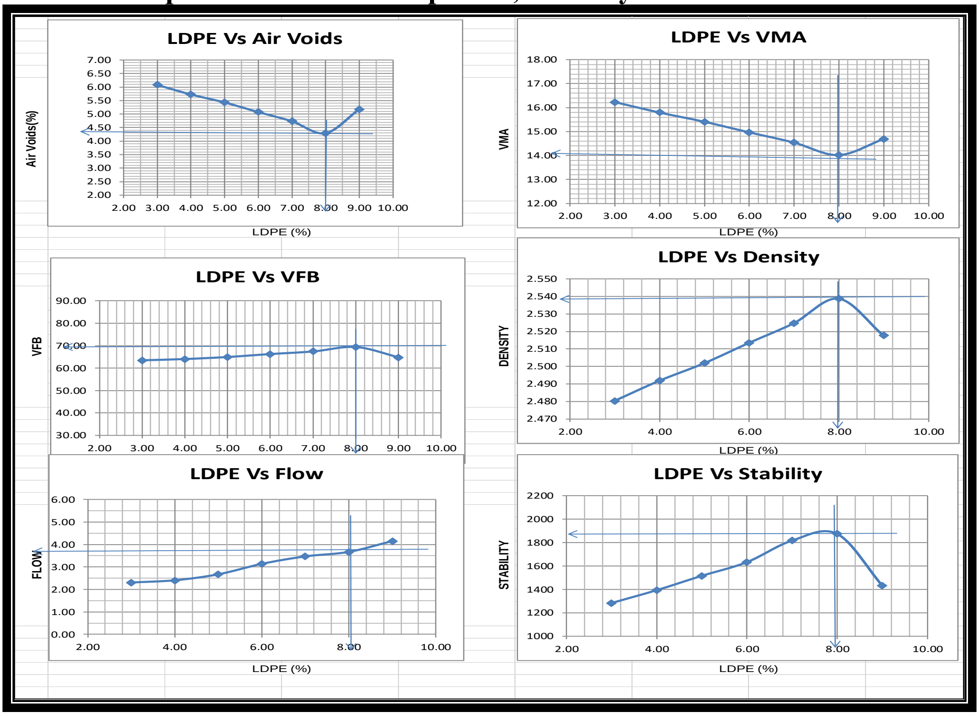
Volumetric and Marshall Tests determined that the Optimum Bitumen Content (OBC) for **Conventional Mix** HMA Concrete to be 5.25%. This OBC evaluated corresponds to a stability factor of 14.16 KN and a flow rate of 3.6 mm. Results evaluated from Table 13 and Fig 10 above.

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

Table 14: 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 Reqd 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 11: Graph of Volumetric Properties, Stability and Flow of LDPE.



3.2.1 Results: It is observed that when LDPE additive is substituted to bitumen in predetermined ratios all the engineering properties undergo a change. The experimental study shows that @ 3% substitution of LDPE the stability measured is 12.56KN. Further increase of

LDPE @5% shows the stability increase to 14.85KN. The observation shows a gradual increase of 17.82KN reaching @7% substitution and reaches a peak of 18.37KN @ 8% substitution of LDPE. However at 9% the stability starts decreasing to 14.02KN.

Similarly, the flow reading @3% LDPE substitution shows a reading of 2.3mm. The Flow reading increases gradually to 2.7mm@ 5% substitution of LDPE. At 8% substitution of LDPE the flow value shows a reading of 3.8mm. Increasing LDPE percentage to further @ 9% LDPE reads a flow value of 4.2mm which is more than the specification limits of 4mm.

The Corresponding values of VIM, VMA and VFB also show similar characteristics of increase when the LDPE percentage is increased. Therefore evaluating from Table 14 and graphs of Fig 11 VIM, VMA, VFB, Stability and flow the **optimum percentage of LDPE** which satisfies all specification and engineering parameters is evaluated at 8% substitution of LDPE.

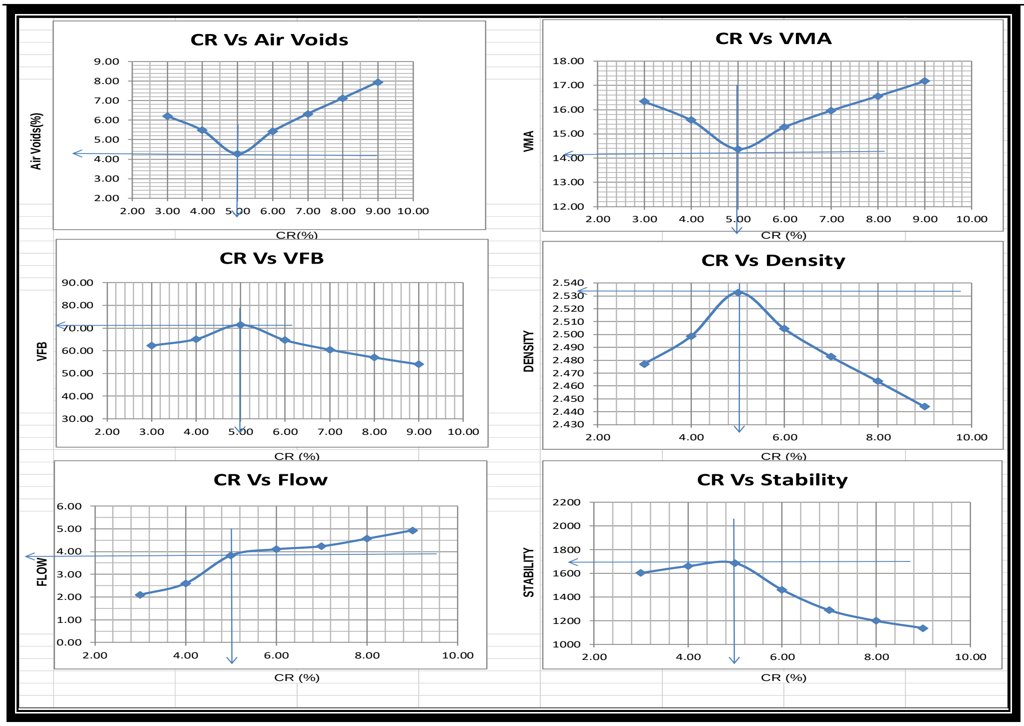
Evaluated OBC for LDPE =8%

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

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

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



3.3.1 Results: It is observed that when Crumb Rubber additive is substituted to bitumen in predetermined ratios all the engineering properties undergo a change. The experimental study shows that @ 3% substitution of Crumb the stability measured is 15.72KN. Further increase of C.R @5% shows the stability increase to 16.54KN. The observation shows that there is a gradual increase till 16.54 KN reaching @5% substitution and reaches a peak. However at 6% substitution of C.R the stability starts decreasing to 14.31KN. It is observed further increase of C.R decreases the stability finally reading at 11.51KN for a substitution of 9%C.R.

Similarly, the flow reading @3% C.R substitution shows a reading of 2.1mm. The Flow reading increases gradually to 3.8 mm@ 5% substitution of C.R. At 7% substitution of C.R the flow value shows a reading of 4.2mm. Increasing C.R percentage to further @ 9% C.R reads a flow value of 4.9mm which is more than the specification limits of 4mm. The Flow value beyond 5% of C.R does not satisfy specification parameters

The Corresponding values of VIM, VMA and VFB also show similar characteristics of increase when the C.R percentage is increased. Therefore evaluating from Table 15 and graphs of Fig 12 VIM, VMA, VFB, Stability and flow the **optimum percentage of Crumb Rubber** which satisfies all specification and engineering parameters is evaluated at 5% substitution of LDPE.

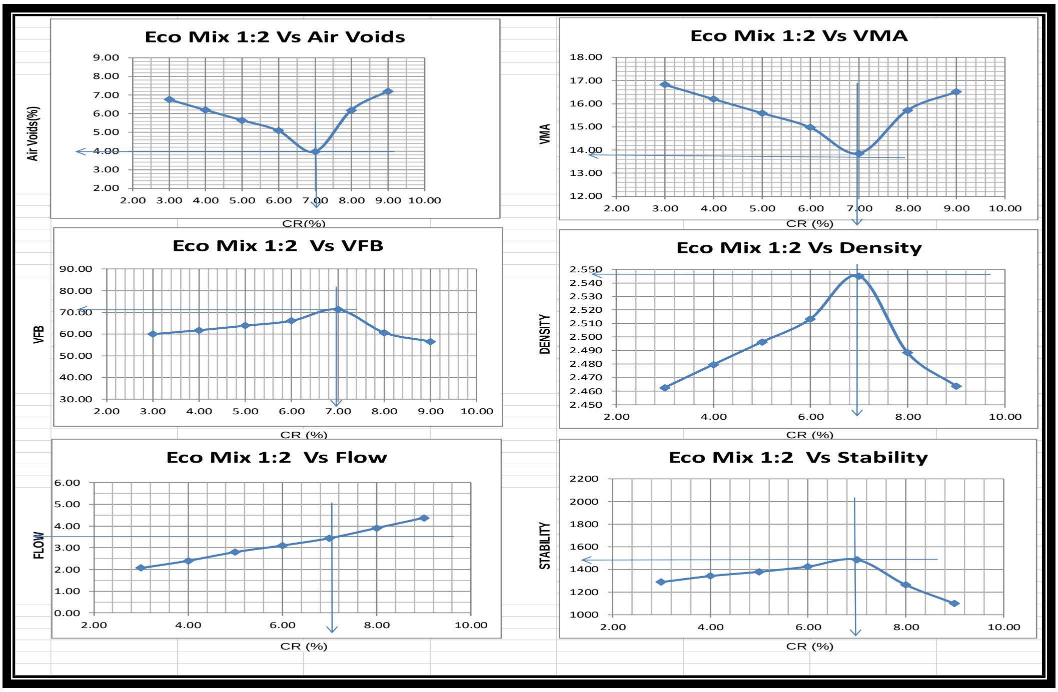
Evaluated OBC for Crumb Rubber =5%

3.4 Volumetric and Marshall values for determining the best Eco Mix2 % to substitute in bitumen

Table 16: Volumetric, Stability and Flow Analysis Marshall Mix Design using ECO MIX 1:2.

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 Reqd 9KN	**Flow (mm) (2-4) mm**
1	3.00 %	2.462	2.641	6.76	16.83	59.97	1288	12.63	2.1
2	4.00 %	2.480	2.643	6.20	16.21	61.80	1341	13.15	2.4
3	5.00 %	2.496	2.646	5.65	15.60	63.89	1378	13.51	2.8
4	6.00 %	2.513	2.648	5.09	14.98	66.12	1424	13.96	3.1
5	**7.00 %**	**2.545**	**2.650**	**3.97**	**13.85**	**71.36**	**1484**	**14.55**	**3.4**
6	8.00 %	2.488	2.653	6.19	15.72	60.66	1263	12.39	3.9
7	9.00 %	2.464	2.655	7.21	16.51	56.58	1098	10.77	4.4

FIG 13: Graph of Volumetric Properties, Stability and Flow of Eco Mix 1:2.



3.4.1 Results: It is observed that when Eco Mix 2 additive is substituted to bitumen in predetermined ratios all the engineering properties undergo a change. The experimental study shows that @ 3% substitution of Eco Mix 2 the stability measured is 12.63KN. Further increase of Eco Mix 2 @5% shows the stability increase to 13.51KN. The observation shows a gradual increase up to 14.55KN reaching @ 7% substitution and reaches a peak. However at 8% of Eco Mix 2 addition the stability starts decreasing to 12.39KN and reaches 10.77KN at 9% additive of Eco Mix 2.

Similarly, the flow reading @3% Eco mix 2 substitution shows a reading of 2.1mm. The Flow reading increases gradually to 2.8mm@ 5% substitution of Eco Mix 2. At 7% substitution of LDPE the flow value shows a reading of 3.4mm. Increasing LDPE percentage to further @ 9% LDPE reads a flow value of 4.4 mm which is more than the specification limits of 4mm.

The Corresponding values of VIM, VMA and VFB also show similar characteristics of increase when the Eco Mix 2 percentage is increased. Therefore evaluating from Table 16 and graphs of Fig 13 VIM, VMA, VFB, Stability and flow the **optimum percentage of Eco Mix 2** which satisfies all specification and engineering parameters is evaluated at 7% substitution of Eco Mix 2.

Evaluated OBC for Eco Mix 2 =7%

3.5. Cost Estimation and Savings

Road Construction.

In India, roads 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.

3.5.1 Cost Savings using Eco Mix 2

By substituting 7% of the bitumen with Eco Mix 2 (1:1 ratio of LDPE 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 17: 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 18: Quantity of Bitumen for Laying Modified Mix 2 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.**

a) Bitumen Requirement for Conventional Road = 21300 Kgs
b) Replacement at 1:2 =7% i.e. 7% of 21300 = **1491 Kgs(** i.e. 2.3% LDPE and 4.7% CR)

c) LDPE Requirement @ 1:2= 2.3% of 21300 = 497 Kgs
d) CR Requirement @ 1:2= 4.7% of 21300 = 994 Kgs.
e) Total Requirement of LDPE (c) +CR (d) = **1491 Kgs.**

f) Quantity of Bitumen Required for New Road using 1:2 = 21300Kgs – 1491Kgs= **19809kgs.**

Table 19: Cost of Bitumen for Laying Eco Mix 2 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 Modified Mix Road	497	16	7952
(iv)	Quantity of Crumb Rubber Consumed in Modified Mix Road	994	13	12922
(v)	Total Costing of asphalt mix For Modified Mix Road	Item (ii)+(iii)+(iv)		**1110369**

- **Total Savings: ₹ 117,150 - ₹ 1,110,369 = ₹ 61,131.**

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

- **Savings per KM: ₹ 61,131.**

Savings Using Eco Mix 1:2 Over Conventional Mix = ₹ 61131 per KM.

- **Percentage Savings per KM = 5.21%.**

Percentage Savings per KM = (₹ 61131÷₹ 1171500) x 100 = 5.21%.

3.5.2 Results: Using Eco Mix 2 in road construction can result in a 5.21% cost savings compared to conventional bitumen. This is primarily due to the reduced bitumen requirement and the inclusion of recycled materials. Also the OBC at 7% replacement satisfy all specification limits and Engineering characteristics.

3.6 Limitations and Futuristic opportunities.

3.6.1 Waste material must be compatible with other HMA components. Particle size, shape, and chemical makeup are all important factors to consider while mixing.

- Strict quality control methods are required to preserve the desirable qualities of the HMA. This includes checking the waste for impurities and ensuring correct mixing and compaction.
- Clearing garbage from landfills is necessary considering the potential environmental implications of employing waste materials in roadways, such as pollutant emission during manufacture or road use. Also Public acceptance of using waste materials in road construction may be a factor to be taken into account.

3.6.2 Further research and development are necessary to fully understand the potential benefits and challenges of using non-biodegradable waste in HMA. Areas of focus should include:

- Detailed characterization of waste materials to identify their suitability for use in HMA.
- Optimization of mixing and compaction processes to ensure the proper incorporation of waste materials into HMA.
- Long-term performance evaluation of roads constructed with Waste-based HMA to assess its durability and sustainability.

IV Conclusion.

(i) Experimental results show that addition of Non Bio-Degradable Additives like LDPE and Crumb Rubber alter the Engineering Properties considerably.

(ii) Replacing Bitumen with 7% Eco Mix 2 increases the stability by 2.75% in comparison to conventional Mix. Also The flow reading of 3.4 shows that Eco Mix 2 has lower tendency to experience permanent deformation in heavy traffic in comparison with Conventional Mix

(ii) Eco Mix 2 which is an effective proportional blend of LDPE and C.R in the ratio 1:2 @7% Bitumen replacement can be considered in providing an effective Job Mix Formula.

(iii) The Job Mix Formula utilising Eco Mix 2 can be considered good alternative for road repairs and laying given its Engineering properties.

(iv) India's moderate to hot tropical climate makes polymer-modified like **Eco Mix 2** an ideal solution. It can also help mitigate the impact of heavy rains and extend the lifespan of roadways. .

(v) Eco Mix 2 gives an overall saving of 5.21% per Km and reduces environmental waste. **Eco Mix 2** makes road construction eco-friendlier and more cost-effective. The reduction in bitumen content can lead to significant savings in road laying expenses and a decrease in environmental waste.

Eco Mix 2, a blend of LDPE and crumb rubber, enhances HMA stability. It's particularly effective in hot, rainy climates and high-traffic areas. Replacing 7% bitumen with Eco Mix 2 improves stability by 2.75%. This sustainable solution reduces environmental waste and lowers road construction costs. Further research and development are necessary to address the challenges and maximize the benefits of this technology.

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