International Journal of Enhanced Research in Science, Technology & Engineering
ISSN: 2319-7463, Vol. 14 Issue 1, January-2025

Building Sustainable Roads by Incorporating Waste Ecoblend in HMA

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ABSTRACT

Integrating circular economy principles into supply chain operations allows enterprises to optimize resource utilization, reduce waste, and promote sustainability. The increasing intensity of traffic requires roads that are stronger, more stable, durable, and sustainable. This experimental study addresses a significant environmental challenge by blending waste plastics (low-density polyethylene, LDPE) and crumb rubber (CR) to enhance bitumen's performance while utilizing low-cost materials. The study experiments an innovative mixture, termed "Ecoblend," which combines LDPE and CR in a 1:2 ratio.

Bitumen is partially replaced with Ecoblend in varying proportions ranging from 3% to 9%, and the resulting samples are evaluated using the Marshall method to analyze volumetric properties, stability, and flow. Experimental findings indicate that incorporating these modifiers significantly improves the engineering properties of bitumen, contributing to the development of more sustainable roads. By adopting circular economy principles and repurposing non-biodegradable waste in road construction, this approach not only addresses environmental concerns but also fosters economic and environmental sustainability.

Keywords: Low-Density Polyethylene (LDPE), Crumb Rubber (CR), Eco-Friendly Roads, Sustainable Pavement, Waste Repurposing in Roads, Green Infrastructure.

INTRODUCTION

The traditional linear economy, characterized by a "take-make-dispose" model, which has led to significant environmental degradation and resource depletion. As global population and consumption patterns continue to grow, the strain on our planet's resources becomes increasingly acute there is a need to ponder on circular economy principles.

Defining the Circular Economy.
The circular economy represents a systemic approach to economic activity aimed at decoupling growth from environmental harm. It is guided by three principles:

1. **Design for the Future**: Developing products that prioritize durability, reparability, and recyclability.
2. **Keep Products and Materials in Use**: Extending product lifecycles through reuse, repair, and refurbishment.
3. **Regenerate Natural Systems**: Reducing environmental impact while actively restoring ecosystems.

Considering a Sustainable Alternative
The circular economy provides a transformative framework for managing resources. It emphasizes prolonging the use of products and materials, maximizing their value, and recovering and regenerating them at the end of their lifecycle.

Transitioning from a linear to a circular model enables businesses to reduce waste, conserve resources, and combat climate change.

Integrating Circular Principles into Supply Chain Management.
Supply chain management is critical in driving the transition to a circular economy. By embedding circular principles into supply chain processes, organizations can optimize resource utilization, reduce waste, and promote sustainability.

This experimental study contributes to this vision by exploring innovative materials for road construction, paving the way for more durable and sustainable infrastructure solutions.

Incorporating Circular Economy Principles to Repurpose Non-Biodegradable Waste in Road Construction
Developing environmentally sustainable roads is a significant challenge in modern road construction. One promising solution is the use of waste materials, such as crumb rubber (CR) and low-density polyethylene (LDPE), as cost-effective alternatives to expensive commercial polymers.

Waste polymers like CR and LDPE can be mechanically blended with bitumen to produce modified bitumen with distinct chemical properties, potentially enhancing its performance and compatibility (Al-Hadidy et al., 2011; Navarro et al., 2009; Martin et al., 2006).

Durable asphalt pavements, typically composed of mineral aggregates, fillers, and high-quality binders, are prepared in hot mix facilities and applied at high temperatures to ensure their strength and longevity. Incorporating waste materials into bitumen can alter its chemical characteristics, potentially improving its performance without compromising infrastructure quality.

This study explores the feasibility of using "**Ecoblend"—**a mix of CR and LDPE—as a bitumen modifier in hot mix asphalt (HMA) concrete.

The research aims to identify the optimal Ecoblend ratio to reduce bitumen consumption while improving road performance. By repurposing non-biodegradable waste, this approach supports cost-effective and environmentally sustainable road construction practices in line with circular economy principles.

IMPORTANCE OF THE EXPERIMENTAL STUDY

Eco Friendly Waste Management:
This study focuses on addressing the environmental challenges posed by non-biodegradable waste by exploring its potential as a source for cost-effective, modified admixtures made from recycled materials.

Enhanced Road Performance:
The research investigates the feasibility of incorporating readily available waste materials into bitumen to improve the durability and overall performance of asphalt roads.

Cost-Effective Solutions:
By extending the lifespan of roads, the use of these enhanced admixtures can reduce maintenance costs and deliver significant long-term financial benefits.

Key Asphalt Pavement Properties:
The quality of asphalt pavement depends on factors such as workability, durability, stability, air void content, and skid resistance. Aggregates, which make up 75-85% of the volume and 90-95% of the weight of asphalt, play a crucial role in its load-carrying capacity. Proper grading and maintaining air voids within the range of 3-5% ensure a dense, impermeable mixture.

This research aims to determine the optimal substitution level of Ecoblend as a bitumen replacement in hot mix asphalt (HMA) concrete. By evaluating and comparing the Marshall characteristics across various replacement percentages, the study seeks to identify the ideal mix for maximizing performance, as detailed in Table 1.

Table 1: Ecoblend Research Gap Comparison Parameters

Ecoblend 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%).

Benefits of a Circular Supply Chain and furure oppurtunities

Benefits of a Circular Supply Chain.	**Future Opportunities.**
Lower Environmental Impact: Minimizes waste generation, decreases carbon emissions, and promotes resource conservation. **IncreasedCost Savings**: Achieves lower energy consumption, reduces waste disposal costs, and enhances operational efficiency. **Improved Public Perception**: Gains recognition for aligning with sustainable and socially conscious values. **Improved Adaptability**: Reduces dependence on finite resources and mitigates risks associated with supply chain disruptions. **Innovation and Employment** : Growth Drives creative solutions, fosters technological advancements, and generates new employment opportunities..	• **Technological Innovations**: Utilizing cutting-edge technologies to enhance supply chain efficiency. • **Policy and Regulatory Encouragement:** Government incentives and regulations supporting the adoption of circular economy practices. • **Innovative Business Models:** Developing new approaches that adhere to circular economy principles. • **Growing Consumer Preference**: Rising demand for sustainable products driven by increased consumer awareness.

Idea Of Creating Circular Plastic Economy **Plastic Waste.**

LITERATURE REVIEW AND EXPERIMENTAL STUDY

This experimental study investigates the combined use of LDPE and crumb rubber as a modifier for asphalt concrete. Previous research shows that adding these materials individually improves strength and stiffness. This experiment explores the effects of varying percentages of both materials, individually and combined, compared to a conventional mix.

Literary Voices in the Public Domain on LDPE + Crumb Rubber as Asphalt Modifier

- **Narendra Parthasarathy, Dr Nitin Bharadiya, Dr P.L.Naktode (2024)**:Experimental results demonstrate that the combination of LDPE and crumb rubber in Eco Mix 2 offers excellent performance in terms of flow and stability. This is particularly beneficial in regions with high temperatures and rainfall.
- **Narendra Parthasarathy, Dr Nitin Bharadiya, Dr P.L.Naktode (2024)**: 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.
- **Narendra Parthasarathy 2023, "Low Density Poly Ethylene(2023)** –The usage of LDPE in village and gram panchayat roads will contribute to lower maintenance costs and a longer lifespan for these roads.We can therefore conclude from the above that LDPE is an effective low-cost modifier
- **Tladi, M., Mashifana, T., & Sithole, N. T. (2023)** investigated the use of plastic waste and waste rubber tires to modify bitumen binders in road construction. They found that increasing the rubber tire content beyond 5% reduced ductility due to the elastic nature of rubber. In contrast, for the bitumen-plastic modified binder, the softening point and ductility showed a directly proportional relationship.
- **Virendra K. Paunikar, Pradeep E. More, and Dr. Ravi W. Tapre (2022)** studied the use of waste plastic and rubber for commercial purposes. Their research examined the interaction between plastic polymers and bitumen in plastic-coated aggregates, which resulted in a strong bond between the materials. This improved the durability of roads and reduced the need for frequent repairs.
- **Gao, B., Zhao, Y., & Zhao, Z. (2023)**. Characteristics of Polyurethane/Waste Rubber Powder Composite Modifier and Its Effect on the Performance of Asphalt Mixture. The study found that the optimal mixing ratio of polyurethane to waste rubber powder is 1:1. However, using too much of this composite modifier can negate the anti-cracking properties of asphalt mixtures.
- **Alemu, G. M., Melese, D. T., Mahdi, T. W., & Negesa, A. B. (2023)**. Combined performance of polyethylene terephthalate waste plastic polymer and crumb rubber in modifying properties of hot mix asphalt.The study found that the best enhancement in hot mix asphalt properties is achieved by using 10% crumb rubber modified asphalt binder and 2% polyethylene terephthalate polymer as a filler material. This combination increases asphalt strength and reduces the likelihood of rutting.
- **Cardoso, J., Ferreira, A., Almeida, A., & Santos, J. (2023)**. Incorporation of plastic waste into road pavements: A systematic literature review on the fatigue and rutting performances.The review found that PET and HDPE plastics generally improve rutting and fatigue performance in road pavements, while LDPE tends to increase rutting and worsen fatigue. Overall, the optimal amount of plastic added is typically small, around 1% of the mixture's weight.
- **Mohan, A., Kumar, R. D., & Satchidanandam, J. (2023).** Simulation for Modified Bitumen Incorporated with Crumb Rubber Waste for Flexible Pavement. The study concluded that adding HDPE and crumb rubber significantly improves the durability and viscoelastic properties of the binder. These improvements were observed when adding 2%, 4%, 6%, 8%, and 10% of crumb rubber and plastic.
- **Ranganathan, A., Sudheerbabu, D., Badulla, N., Tejaswini, T., Nagarjuna, D., & Durgaprasad, Y. V. (2023).** Analysis of Bituminous Concrete Mixes Using HDPE & Crumb Rubber as Admixtures. The study found that adding 8% shredded HDPE to bituminous concrete mix significantly improved its Marshall Stability, thereby increasing its rutting resistance and load-carrying capacity. Additionally, the stability of the mix continued to increase as the amount of HDPE was raised proportionally up to 10%.
- **Al-Fatlawi, S. A., Al-Jumaili, M. A., Eltwati, A., & Enieb, M. (2023).**Experimental-numerical model of permanent deformation in asphalt paving mixtures modified with waste plastic and rubber.The study compared three types of asphalt cement: a neat binder (VB), VB with 3% waste plastic (WP), and VB with 15% crumb rubber (CR). It found that asphalt mixtures modified with WP and CR (for the base course) using coarse aggregate gradation demonstrated greater resistance to rutting than unmodified mixtures prepared with fine or coarse aggregate gradation.
- **Chen, G., Peng, Y., Yang, N., Xu, G., Gong, K., & Xu, X. (2023).** Innovative Use of Waste PET-Derived Additive to Enhance Application Potentials of Recycled Concrete Aggregates (RCA) in Asphalt Rubber. The study concluded that waste PET-derived additives can be effectively used to improve the recycling of RCA in asphalt pavement on a larger scale. These additives offer several advantages, especially in terms of enhancing moisture-induced damage resistance.

- **Gurpreet Singh, Rajiv Chauhan (2021).** Sustainable Use of Plastic Waste and Crumb Rubber in Bituminous Concrete Production: The study partially replaced bitumen with waste plastic (3-11%) and crumb rubber (4-20%) using bitumen grade 80/100. The study analyzed and concluded that adding plastic and crumb rubber to bituminous concrete production can significantly improve the engineering properties of the pavement and enhance sustainable construction.

METHODOLOGY

Preparation Methodology: Experimental Samples / Modified Bitumen Mix Design

The mix design process involves combining various materials—coarse aggregate, fine aggregate, filler, and bitumen—in precise proportions at a specified temperature to produce bituminous concrete (BC). This process is suitable for both dense-graded bituminous macadam (DBM) and open-graded BC courses. The proportions of bitumen and modifiers are carefully calculated to create a high-quality mixture that meets engineering requirements.

Preparation of Experimental Samples / Modified Bitumen

The preparation process includes blending coarse aggregate, fine aggregate, filler, and bitumen at specific proportions and temperatures during the casting of molds. Two primary methods are used for blending bitumen with modifiers:

- **Dry Process**: Recommended for plastics that enhance rutting and moisture resistance in asphalt pavements.
- **Wet Process**: Preferred for plastics with low melting points, improving the binder's moisture resistance, rutting, and fatigue properties.

Given the use of low-density polyethylene (LDPE) in this study, the wet process was selected for the Marshall mix design to evaluate the Marshall properties of the mixtures.

Determination of OBC for Conventional Mix

In this methodology, the wet process is employed for the Marshall mix design to assess the Marshall properties of LDPE-modified mixtures. The first step involves determining the optimum bitumen content (OBC) for the conventional mix, which was found to be 5.25%.

Subsequently, LDPE and bitumen were blended in predetermined percentages to evaluate stability and flow. The same procedure was applied for crumb rubber (CR). A mixture of LDPE and CR in a 1:2 ratio, termed **Ecoblend**, was then prepared. The Ecoblend was combined with bitumen in various proportions to analyze stability and flow characteristics, as outlined in Table 2.

Materials Used

- Bitumen (VG40): The primary binder in the Hot Mix Asphalt (HMA) mixture, offering properties like surface wear resistance, water infiltration reduction, smooth finish, and structural support.
- Coarse Aggregate: Particles larger than 13mm, conforming to MORTH specifications.
- Fine Aggregate: Particles smaller than 4.75mm, meeting MORTH specifications, with sieve sizes of 4.75mm and 2.36mm.
- Dust: Quarry stone particles finer than 2.36mm.
- Low-Density Polyethylene (LDPE): A thermoplastic polymer derived from ethylene, suitable for the experiment due to its heat resistance up to 80-95°C.
- Crumb Rubber (CR): Recycled material from waste tires, providing beneficial properties when modified with bitumen for HMA.

Initial Steps

1. **Aggregate Preparation**: Coarse and fine aggregates were thoroughly washed to remove dust and properly graded.
2. **Mixing for Conventional Mix**: Aggregates were blended with bitumen to determine the optimum bitumen content (OBC) for the conventional mix.
3. **OBC Determination**: Hot mix asphalt (HMA) for the conventional mix was prepared in the laboratory, and the OBC was evaluated to be 5.25%, as shown in Table 4.

Experimental Steps

1. **Preparation of Experimental Mixes**: Experimental mixes incorporating crumb rubber (CR) and low-density polyethylene (LDPE) were prepared as per Table 2.
2. **LDPE Replacement**: LDPE was blended with bitumen in varying percentages (3% to 9%) to study its performance characteristics, with results recorded in a tabular format.

3. **CR Replacement**: Similarly, CR was substituted for bitumen in varying percentages (3% to 9%) to evaluate its performance, with results tabulated.
4. **Ecoblend Substitution**: A mix of LDPE and CR in a 1:2 ratio (Ecoblend) was combined with bitumen in varying proportions (3% to 9%) as per Table 2. Performance characteristics were analyzed, and results were tabulated.

Experimental Programme

1. **Marshall Mix Preparation**: Bitumen was blended with predetermined ratios (as shown in Table 2) to prepare experimental Marshall mix samples. Marshall tests, including volumetric stability and flow analysis, were conducted for all samples. Test percentages were selected based on prior evaluations of waste plastics and crumb rubber.
2. **Experimental Design Summary**: The experimental design, including proportions and test outcomes, is detailed in Table 2.

Mix Design and Preparation

- **Conventional Mix Design**: A traditional mix design methodology was employed to create flexible pavement mixtures for Dense Bituminous Macadam (DBM) and Base Course (BC). This involved blending coarse aggregate, fine aggregate, filler, and bitumen in precise proportions at the required temperature during casting.
- **Modified Bitumen Preparation**: The wet process was utilized to incorporate LDPE and crumb rubber into the bitumen. This method, suitable for plastics with low melting points, enhances moisture resistance, rutting performance, and fatigue resistance of binder blends.
- The Marshall methodology allowed for a comprehensive assessment of the impact of LDPE and Crumb Rubber on the engineering characteristics of HMA concrete.

Table 2: Bitumen Additive percentage for LDPE: Crumb Rubber & Ecoblend

No.	Bitumen% + Additive % (X %) + (-Y %)	LDPE	Crumb Rubber	Ecoblend
	Bitumen% + Additive (LDPE/C.R/1:2)%	Sample LDPE	Sample CR	Sample Ecoblend1:2
1	OBC % + (- 3%)	Sample A	Sample B	Sample C
2	OBC % + (- 4%)	Sample A1	Sample B1	Sample C1
3	OBC % + (- 5%)	Sample A2	Sample B2	Sample C2
4	OBC % + (- 6%)	Sample A3	Sample B3	Sample C3
5	OBC % + (- 7%)	Sample A4	Sample B4	Sample C4
6	OBC % + (- 8%)	Sample A5	Sample B5	Sample C5
7	OBC % + (- 9%)	Sample A6	Sample B6	Sample C6

Table 3: Volumetric propertie

Theoretical specific gravity	**Gt**
Bulk specific gravity of the mix	**Gm**
Percent air voids	**Vv**
Percent volume of bitumen	**Vb**
Percent void in mineral aggregate	**VIM**
Percent void in mixed aggregate	**VMA**
Percent voids filled with bitumen	**VFB**

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ISSN: 2319-7463, Vol. 14 Issue 1, January-2025

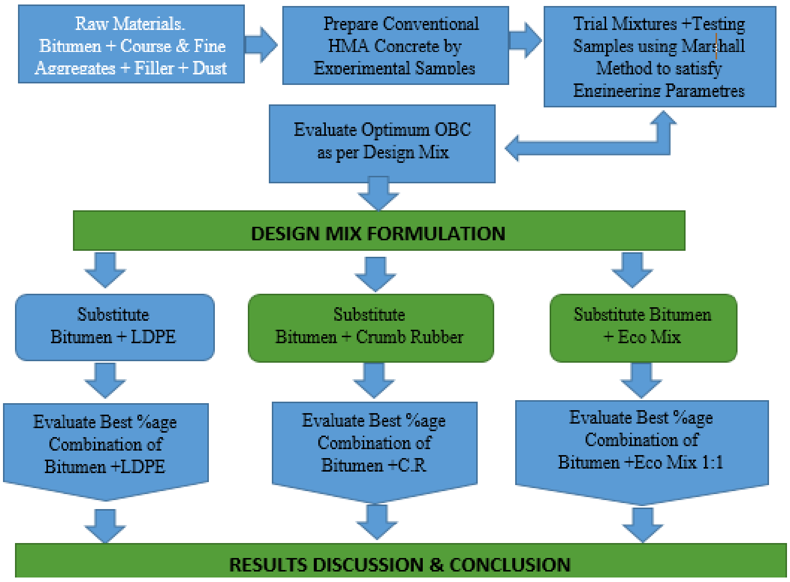

Fig 1: Flow Chart Design Mix Formulation and Evaluation

Marshall Flow Properties of Mix: Volumetric Properties + Stability + Flow
Volumetric Properties of the mix: The Volumetric properties that are of interest include the7 properties mentioned in Table 3.

TESTS AND RESULTS

Marshall Values for Determining OBC Of HMA Bitumen Concrete Using VG40

Table 4: Density and Void Analysis for Control Mix for Determining OBC

S.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 Required 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

Marshall Values For Determining OBC of HMA Substituted With LDPE

Table 5: Volumetric, Stability and Flow Analysis Marshall Mix Design using LDPE

S.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 Required 9KN	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	17.81	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

Marshall Values for Determining OBC of HMA Substituted With Crumb Rubber.

Table 6: Volumetric, Stability and Flow Analysis Marshall Mix Design using Crumb Rubber

S.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 Required 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

Marshall Values for Determining OBC Of HMA Substituted WithEco Blend 1:2.

Table 7 : Volumetric, Stability and Flow Analysis Marshall Mix Design using Ecoblend 1:2

S.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 Required 9KN	Flow (mm) (2-4)mm
1	3.00 %	2.462	2.641	6.76	16.83	59.97	1288	12.63	2.10
2	4.00 %	2.480	2.643	6.20	16.21	61.80	1341	13.15	2.40
3	5.00 %	2.496	2.646	5.65	15.60	63.89	1378	13.51	2.80
4	6.00 %	2.513	2.648	5.09	14.98	66.12	1424	13.96	3.10
5	**7.00 %**	**2.545**	**2.650**	**3.97**	**13.85**	**71.36**	**1484**	**14.55**	**3.40**
6	8.00 %	2.488	2.653	6.19	15.72	60.66	1263	12.38	3.90
7	9.00 %	2.464	2.655	7.21	16.51	56.58	1098	10.76	4.40

MARSHALL MIX DESIGN AND THE IMPACT OF POLYMER ADDITIONS

Key Findings:

- **LDPE** demonstrated the most significant improvement in Marshall stability.
- **CR** also had a positive effect on stability.
- **The blended mix** suggested to reduce cost and acceptable engineering properties.

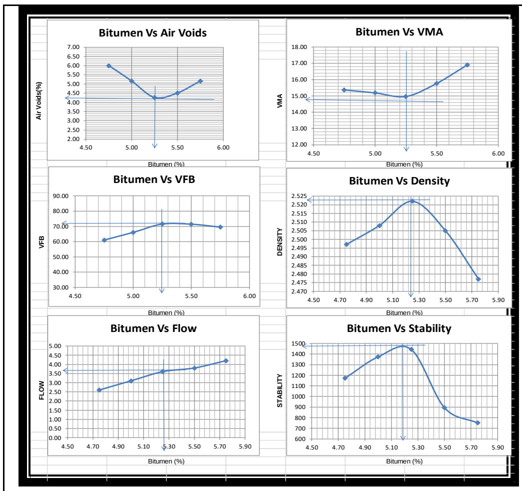

Fig 2: Graph of Stability and Flow of Conventional Mix to find OBC

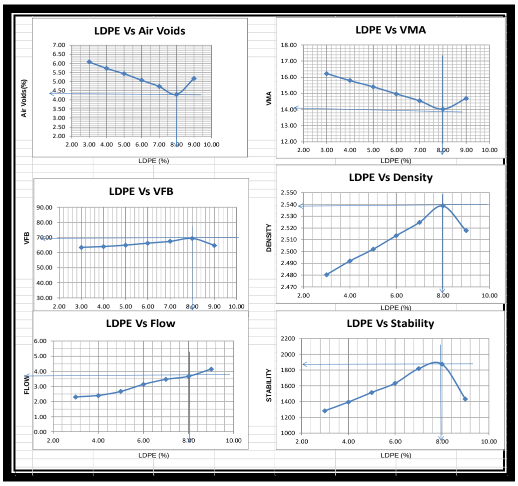

Fig 3: Graph of Volumetric Properties, Stability and Flow of LDPE.

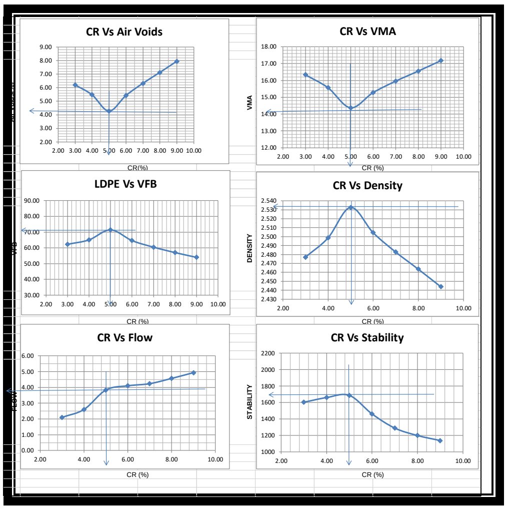

Fig 4: Graph of Volumetric Properties, Stability and Flow of Crumb Rubber.

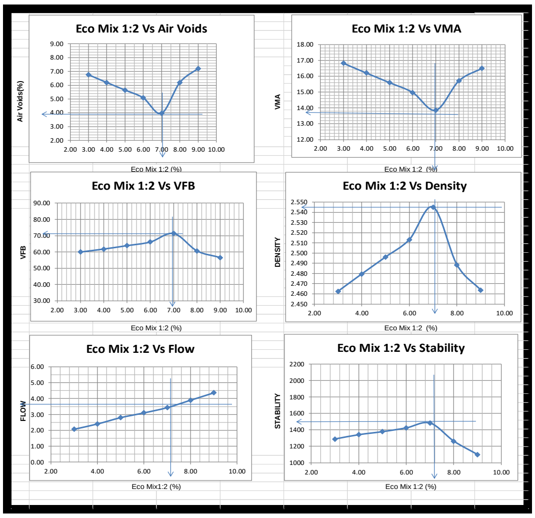

Fig 5: Graph of Volumetric Properties, Stability and Flow of Ecoblend 1:2

Cost of laying Bitumen for New Road using Ecoblend. LDPE: CR =1:2.

I. Bitumen Requirement for New Road = 21300 Kgs
II. Replacement at 1:2 =7% i.e. 7% of 21300 = **1491 Kgs(** i.e. 2.0% LDPE and 4.0% CR)
III. LDPE Requirement @ 1:2= 2.0% of 21300 = 497 Kgs
IV. CR Requirement @ 1:2= 4.0% of 21300 = 994 Kgs.
V. Total Requirement of LDPE (c)+CR (d) = **1491 Kgs**
VI. Qty of Bitumen Required for New Road using 1:1 = 21300Kgs – 1491Kgs= **19809kgs**

Cost of Bitumen for Laying Eco Mix 2 Road

Item	Description	QTY(Kgs)	Per/Kg	AMT (₹)
13	Quantity of Bitumen in 1km Modified mix road @3.75m Width	19809	55	1089495
14	Quantity of LDPE Consumed in Modified Mix Road	497	16	7952
15	Quantity of Crumb Rubber Consumed in Modified Mix Road	994	13	12922
16	Total Costing of asphalt mix For Modified Mix Road			**1110369**

Total Savings Using Eco Mix 2 = Item (i) – Item (v) = ₹ 1171500 - ₹ 1110369. = ₹ 61131.
Savings Using Eco Mix 2 Over Conventional Mix = ₹ 61131 per KM
Percentage Savings per KM = (₹ 61131 ÷₹ 1171500) x 100 = 5.21% : Percentage Savings per KM = 5.21 %

CONCLUSION

Enhanced Sustainability and Durability: The experiment demonstrated that incorporating Ecoblend into bitumen reduces pavement voids, improving durability and making it a viable option for harsh climates.

LDPE Advantages: Replacing 7% of bitumen with LDPE in hot mix asphalt (HMA) significantly enhances engineering properties, particularly in regions with high temperatures and heavy tropical rainfall.

Crumb Rubber Advantages: Substituting 5% of bitumen with crumb rubber in HMA improves engineering characteristics, making it especially suitable for areas with heavy traffic loads.

Ecoblend Benefits: The experimental results revealed that the combination of LDPE and crumb rubber in Ecoblend provides excellent flow and stability performance, especially in regions with high temperatures and heavy rainfall.

Climate Suitability of Ecoblend: In India's tropical climate, polymer-modified pavements are highly effective. Adding 2.33% LDPE and 4.67% crumb rubber to bitumen yields superior flow and stability results, making it an ideal solution for mitigating the impacts of heavy rains and extending road lifespans.

Optimal Blend Recommendation: The study suggests that an optimal blend of Ecoblend (1:2 ratio of LDPE to crumb rubber) at a 7% replacement of bitumen content is effective. This practical mix utilizes 2.33% LDPE and 4.67% crumb rubber, replacing 7% of the bitumen in the asphalt mix. It not only recycles plastic and rubber waste but also reduces overall bitumen usage, offering durable roads and addressing issues of pavement deterioration. This mix is particularly suitable for district and panchayat roads where regular maintenance is challenging.

Eco-Friendly, Environmental, and Economic Benefits: Using Ecoblend in road construction enhances sustainability and cost-efficiency by lowering bitumen content. This approach can achieve a cost saving of **5.21% per kilometer of road**, while simultaneously reducing environmental waste.

Promoting a Circular Economy: By adopting circular economy principles and sustainable supply chain practices, this approach reduces waste, conserves resources, and mitigates climate change, paving the way for a more resilient and equitable future for generations to come.

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