PERFORMANCE EVALUATION AND SUSTAINABILITY ASSESSMENT OF FLEXIBLE PAVEMENT MODIFIED WITH WASTE PLASTIC (LDPE) AND WASTE COOKING OIL (WCO)

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Abstract - *There is an urgent demand for sustainable and affordable building materials due to the quick development of transportation infrastructure and the rising production of non-biodegradable waste. The possible employment of waste cooking oil (WCO) and waste plastic (WP) as modifiers in bituminous mixes for flexible pavement applications is examined in this study. The main goal is to assess a composite-modified binder's performance and environmental advantages. Low-Density Polyethylene (LDPE) is added to improve pavement rigidity and rutting resistance, though plastic alone increases binder brittleness. Waste cooking oil is incorporated as a rejuvenating agent to enhance workability, flexibility, and resistance to low-temperature cracking. The study combines both modifiers to achieve the optimal balance between strength and flexibility. Lab evaluations via Marshall Stability, flow value, and volumetric properties confirm that using 6% LDPE and 3% WCO in VG-30 bitumen boosts stability by ~75% (to 14.04 kN) while maintaining desirable ductility and flow. This strategy reduces material costs, promotes waste reuse in road construction, and mitigates environmental pollution.*

Key Words: Flexible Pavement, Waste Plastic (LDPE), Waste Cooking Oil (WCO), Marshall Stability, Rejuvenating Agent, VG-30 Bitumen, Sustainable Construction.

1. INTRODUCTION

1.1 General

The need for long-lasting and reasonably priced road infrastructure has grown dramatically due to rapid urbanization and industrial expansion. At the same time, the accumulation of non-biodegradable trash and depletion of natural resources have become significant global issues. Bitumen is the primary binding substance used in flexible pavements, but conventional bitumen suffers from temperature susceptibility rutting at high temperatures and cracking at low temperatures [1].

Plastic debris (especially Low-Density Polyethylene - LDPE) and waste cooking oil (WCO) demonstrate great potential for bitumen modification. LDPE increases structural rigidity and rutting resistance, but excessive stiffness causes fatigue brittleness [2]. Conversely, WCO contains fatty acid components that rejuvenate the oxidized binder matrix, lowering viscosity and enhancing flexibility [3]. Combined utilization yields a balanced binder system that overcomes individual material limitations.

1.2 Background of Waste Plastic in Pavements

The utilization of plastic waste in road construction began in the 1990s as an alternative resource recovery method. Plastic coats aggregates or blends with bitumen, enhancing adhesion and water resistance [4]. In India, guidelines (IRC:SP:98) support waste plastic integration to transform environmental hazards into high-performing road assets.

1.3 Background of Waste Cooking Oil (WCO)

Improper WCO disposal causes water pollution and drainage blockage. Early 2000s research identified WCO fatty acids as excellent bio-rejuvenators for asphalt binders, reducing viscosity and improving ductility during construction compaction [5].

1.4 Application Methods

Dry Process: Shredded plastic is mixed directly with hot aggregates to create a thin protective coating before adding bitumen.

Wet Process: Plastic waste and WCO are blended directly into hot bitumen (160–170°C) to produce a homogenous modified binder system (adopted in this study).

2. OBJECTIVES & STUDY NEED

While individual modifier effects are documented, research on the synergistic composite effect of LDPE and WCO remains limited. This study addresses key objectives:

- Evaluate physical & rheological properties of modified VG-30 bitumen.
- Determine optimal modifier dosage for maximum stability and flow.
- Evaluate Marshall volumetric properties (Air voids, VMA, VFB).
- Assess economic and environmental benefits per ton of mix.

3. LITERATURE REVIEW

Gaur et al. (2021) reported that waste plastic enhances binding strength and rutting resistance [6]. Mashaan & Chamlagai (2025) confirmed elevated softening points with PET and LDPE modifiers [7]. Al Mamun et al. (2020) verified that WCO enhances low-temperature flexibility and cracking resistance [8]. Li et al. (2025) demonstrated that composite plastic-oil modification produces balanced rheological performance across fluctuating thermal regimes [9].

4. METHODOLOGY

4.1 Material Characterization

Conventional VG-30 bitumen was selected as the base binder. Physical tests were conducted in accordance with IS standards.

Table -1: Physical Properties of VG-30 Bitumen

Property	Test Value	IS Requirement (IS 73)
Penetration (0.1 mm)	65	50 - 70
Softening Point (°C)	48	Min 47
Ductility (cm)	78	Min 40
Viscosity at 60°C (cP)	420	Min 300

Table -2: Properties of Coarse Aggregates

Property	Test Value	Specification
Aggregate Impact Value	18.2%	Max 24%
Los Angeles Abrasion	22.5%	Max 30%
Specific Gravity	2.68	2.5 - 3.0
Water Absorption	0.45%	Max 2.0%

4.2 WCO Pretreatment Process

Collected WCO was filtered through fine mesh to remove food particles, then dehydrated at 105–110°C to eliminate residual moisture before blending.

4.3 Mix Design & Calculations

Bituminous Concrete (BC) specimens (1200g aggregates) were prepared with 5.5% optimum bitumen content (OBC = 66g). LDPE and WCO dosages were calculated by weight of bitumen:

Sample Mix Calculations:

- Bitumen Weight (Wb) = (5.5 × 1200) / 100 = 66.0 g
- Plastic (8% LDPE) (Wm) = (8 × 66) / 100 = 5.28 g
- Oil (3% WCO) (Ww) = (3 × 66) / 100 = 1.98 g
- Total Modified Binder = 73.26 g

Volumetric Relations:

- Marshall Stability = Proving Ring Reading × 0.27 kN
- Bulk Density (Gmb) = Wair / (Wair - Wwater)
- Air Voids (Va) = [(Gmm - Gmb) / Gmm] × 100

5. RESULTS AND DISCUSSION

Laboratory testing evaluated binder physical properties and Marshall performance across various modifier blend percentages.

Table -3: Physical Properties of Modified Bitumen

Blend Designation	Penetration (0.1mm)	Softening Pt (°C)	Ductility (cm)
VG-30 (Base)	65	48	78
VG-30 + 4% LDPE + 2% WCO	60	52	72
VG-30 + 6% LDPE + 3% WCO	55	60	68
VG-30 + 8% LDPE + 4% WCO	50	64	61

Table -4: Marshall Test & Volumetric Results

LDPE + WCO (%)	Stability (kN)	Flow (mm)	Density (g/cc)	Air Voids (%)
0% + 0%	8.0	2.5	2.35	4.8
4% + 2%	11.5	3.0	2.40	4.2
6% + 3%	14.0	3.5	2.44	3.8
8% + 4%	12.2	4.0	2.41	4.1

Discussion: Addition of 6% LDPE elevated stability from 8.0 kN to 14.0 kN (~75% increase) due to enhanced binder stiffness and aggregate interlocking. Beyond 6%, excessive binder stiffness reduced compaction efficiency. WCO restored binder flexibility, elevating flow from 2.5 mm to 3.5 mm while maintaining air voids within the ideal 3.5–4.5% range.

6. ENVIRONMENTAL & COST ANALYSIS

Utilizing 5–8 kg waste plastic and 2–3 liters WCO per ton of bituminous mix significantly replaces virgin bitumen binder. This provides dual environmental relief by diverting plastic from landfills and preventing commercial oil runoff into municipal water systems.

7. CONCLUSIONS

- Composite modification using 6% LDPE and 3% WCO delivers optimal structural stability (14.0 kN) and ductility.
- WCO effectively counteracts plastic brittleness, providing superior rutting and thermal cracking resistance.
- The proposed green mix provides a durable, cost-effective, and environmentally sustainable solution for modern flexible pavement construction.

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