Sustainable Road Maintenance: Evaluating Recycled Plastic-Coated Aggregates (PCA) for Enhanced Pothole Repair

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***Abstract*—The rapid deterioration of road infrastructure, exacerbated by monsoon-induced water ingress and heavy vehicular loading, remains a significant challenge for global economic progress and public safety. Simultaneously, the accumulation of non-biodegradable plastic waste (LDPE, HDPE, and PP) presents a severe environmental crisis. This research explores the technical, chemical, and economic integration of these two challenges by evaluating the use of Plastic-Coated Aggregates (PCA) for localized pothole repair. Utilizing a "Dry Process" where shredded plastic waste (by weight of bitumen) is coated onto aggregates heated to , the study assesses mechanical strength, hydrophobic properties, and long-term durability. Laboratory results indicate a increase in Marshall Stability, a reduction in water absorption, and a significant improvement in the Interfacial Transition Zone (ITZ) compared to conventional VG-30 bitumen mixes. Field implementation over a 180-day cycle showed zero pothole reformation. The study concludes that the PCA method offers a technically superior, cost-effective (savings), and environmentally sustainable alternative to traditional bitumen patching, effectively creating a circular economy for low-value plastics.**

***Index Terms*—Plastic Roads, Pothole Repair, Plastic-Coated Aggregates (PCA), Sustainable Construction, Marshall Stability, Bitumen Stripping, Circular Economy, Hydrophobic Coatings.**

I. Introduction

India’s economic growth is intrinsically linked to its 6.3 million kilometer road network, the second-largest in the world. However, the "Monsoon Pothole" cycle has become an annual fiscal drain for municipal corporations and a primary cause of road fatalities. Potholes are primarily formed when water penetrates the pavement surface, weakening the sub-base and causing the bitumen to "strip" or peel away from the aggregate surface under the hydraulic pressure of vehicular tires.

1.1 The "Murum Myth" and Failure of Traditional Repairs

Traditional pothole repair in many developing regions relies on "Murum" (laterite soil) or basic cold-mix patches applied during active rain. This research addresses the "Murum Myth"—the false belief that temporary soil-based filling is a viable stop-gap. Soil is highly hydrophilic; it absorbs water, expands, and turns into slush. Under vehicular loading, this slush is ejected, leading to larger, deeper craters within days.

1.2 The Chemistry of Failure

The fundamental cause of pothole formation is the loss of adhesion between the bitumen (binder) and the stone (aggregate). Bitumen is naturally acidic, and many aggregates are also acidic or have high surface moisture. In the presence of water, the bond breaks (stripping). This study proposes the transition to

Plastic-Waste-Modified Bitumen (PWMB) technology. By utilizing non-recyclable thin films (LDPE/PP), we create a hydrophobic barrier. The polymer coating "seals" the micro-pores of the aggregate, preventing the chemical stripping of bitumen.

II. Comprehensive Literature Review

The application of polymers in bitumen modification has evolved from simple additives to complex structural enhancements.

- **Process Differentiation:** Vasudevan et al. (2006) established the "Dry Process" (coating aggregates first) as superior to the "Wet Process" (blending plastic into bitumen). In the Dry Process, the plastic forms a physical bond with the stone, essentially creating a "new" aggregate with enhanced properties.
- **Polymer Selection:** Studies by Justo & Veeraragavan (2002) identified that LDPE (Low-Density Polyethylene) and PP (Polypropylene) are the most effective due to their melting points (115 DEGREESTO 160 DEGRESS), which align with standard hot-mix temperatures.
- **Durability and Rutting:** Sharma & Gawande (2019) utilized wheel-tracking tests to show that plastic-modified roads exhibit 2.5times more resistance to permanent deformation (rutting) compared to conventional VG-30 bitumen.

III. Methodology and Material Characterization

3.1 Material Standards

1 **Plastic Waste:** Post-consumer waste (LDPE/PP milk pouches and carry bags) was shredded to pass through a 4.75mm sieve. The specific gravity of the shredded plastic was measured at $0.92 - 0.95$.

2 **Bitumen:** Viscosity Grade (VG-30) bitumen was used. Softening point: 48°C; Penetration value: 65mm.

3 **Aggregates:** Crushed granite was tested per IRC:60 standards.

Aggregate Impact Value (AIV): 24.5%

Los Angeles Abrasion Value: 28%

Specific Gravity: 2.68

3.2 Experimental Setup: The Dry Process Protocol

The research utilized a refined five-step laboratory protocol to ensure uniform coating:

1. **Sieving and Cleaning:** Aggregates were washed and dried to 0% moisture content.
2. **Pre-heating:** Aggregates were heated to 170°C in a rotary mixer.
3. **Polymer Injection:** Shredded plastic (7.5% by weight of bitumen) was added. The temperature must stay above 160°C to ensure the polymer transcends its glass transition phase and flows into aggregate crevices.
4. **Bitumen Blending:** Hot VG-30 bitumen (160°C) was added. The plastic-coated stones immediately bonded with the bitumen, creating a thicker binder film.

5. **Compaction:** Marshall specimens were prepared using 75 blows on each face, simulating heavy traffic conditions.

IV. Results and Discussion

4.1 Comparative Mechanical Analysis

Analytical Discussion: The 25% increase in Marshall Stability is a result of the "Plastic Bridge" effect. The polymer film on the aggregate creates a rougher micro-texture, increasing the internal friction angle (ϕ) of the mix. Furthermore, the reduction in air voids (3.8%) without increasing bitumen content suggests that the molten plastic acts as a secondary filler, plugging capillary gaps that would otherwise allow water ingress.

4.2 Thermal Susceptibility

In tropical climates, road temperatures can exceed $60^{\circ}\mathrm{C}$, causing bitumen to soften and "bleed." The PCA mix showed a higher softening point. The incorporated polymer increases the stiffness of the binder at high temperatures while maintaining flexibility at lower temperatures, effectively widening the performance grade (PG) of the pavement.

V. Economic and Socio-Economic Feasibility

5.1 Direct Cost-Benefit Analysis (per $10\mathrm{m}^2$ repair)

- **Bitumen Reduction:** By replacing 7.5% of the bitumen with plastic waste (which is significantly cheaper), the total binder cost drops.
- **Labor Efficiency:** PCA patches require less frequent replacement. A "repair once" approach reduces the recurring labor costs associated with annual monsoon patching.

Note: When factoring in the $3\times$ longer lifespan of the PCA patch, the **Lifecycle Cost Saving** exceeds 45%.

VI. Field Performance and Environmental Impact

6.1 180-Day Field Trial

A pilot study was conducted on an urban arterial road (ADT: $20,000$).

- **Visual Inspection:** After one full monsoon season ($1200\mathrm{mm}$ rainfall), PCA patches showed no signs of "ravelling" (loss of aggregate) or edge-separation.
- **Skid Resistance:** British Pendulum Number (BPN) remained at 65, well above the safety limit of 45, proving that the plastic coating does not make the road slippery.

6.2 The Circular Economy and Microplastics

A critical concern in plastic roads is the potential for microplastic shedding. This research conducted "Leachate Tests" by soaking PCA samples in distilled water for 30 days.

- **Findings:** No detectable polymer fragments were found in the leachate. The plastic is thermally bonded and encapsulated within the bitumen matrix, making it chemically stable.

- **Landfill Diversion:** For every 1km of single-lane road repaired/constructed with this method, 1 tonne of plastic is diverted from oceans and landfills.

VII. Conclusion and Future Scope

The evaluation of Recycled Plastic-Coated Aggregates (PCA) confirms it as a "Triple-Win" solution: technically superior, economically viable, and environmentally restorative.

7.1 Major Technical Findings

1. **Hydrophobic Barrier:** The polymer coating effectively renders the aggregate water-resistant, eliminating the root cause of stripping.
2. **Structural Enhancement:** Increased Marshall Stability allows for thinner pavement layers or higher load capacities.
3. **Interface Integrity:** PCA patches exhibit superior bonding with old pavement edges, preventing the common "ring-crack" failure.

7.2 Strategic Recommendations

- **Standardization:** The Indian Roads Congress (IRC: SP:98) guidelines should be updated to specifically include "Pothole Repair Protocols" using PCA.
- **Mobile Processing Units:** Development of truck-mounted "Pothole Injection Systems" that can heat aggregates and apply plastic coating on-site would revolutionize municipal maintenance.

Cold-Mix Innovation: Future research should investigate using emulsified bitumen with plastic-coated aggregates for "Emergency Repairs" during active rainfall.

References

[1] **Vasudevan, R., et al. (2006).** *Utilization of Waste Plastics in Construction of Flexible Pavements*. International Journal of Environmental Science and Engineering.

[2] **IRC: SP: 98-2013.** *Guidelines for the Use of Waste Plastic in Hot Bituminous Mixes in Wear Courses*. Indian Roads Congress.

[3] **Justo, C.E.G., & Veeraragavan, A. (2002).** *Utilization of Waste Plastic Bags in Bituminous Mix for Improved Performance of Roads*. Centre for Transportation Engineering, Bangalore University.

[4] **Sharma, G., & Gawande, A. (2019).** *Performance Evaluation of Plastic Modified Bituminous Concrete Mix*. International Journal of Engineering Research & Technology.

[5] **Patil, S., et al. (2020).** *Investigation on Pothole Repair using Plastic-Coated Aggregates*. International Journal of Civil Engineering and Technology (IJCIET).

[6] **ASTM D6927-15.** *Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures*.