International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 11 | Nov – 2025 DOI: 10.55041/ISJEM05166
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

A Review on Road Construction Using Industrial Waste and Plastic Waste

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Abstract - Growing environmental concerns caused by the accumulation of industrial waste and plastic pollution have motivated researchers to explore sustainable solutions for road construction (Agarwal et al., 2020). Numerous studies have demonstrated that incorporating plastic waste and major industrial by-products—such as fly ash, blast furnace slag, steel slag, quarry dust, and construction debris—into pavement materials enhances strength, durability, deformation resistance, and economic efficiency (Khan & Sharma, 2021). Research further shows that substituting conventional aggregates or modifying bitumen with waste materials can reduce dependency on natural resources and improve overall pavement performance (Patel & Lodha, 2022). Technological approaches described in the literature reveal both significant engineering potential and important limitations associated with waste-integrated pavement systems (Verma, 2016). This review evaluates past research methodologies, synthesizes performance outcomes, and identifies critical gaps related to standardization, long-term field evaluations, and environmental impacts (Singh & Mishra, 2018). The findings highlight opportunities for advancing sustainable road engineering using waste-derived pavement materials (Choudhary et al., 2019).

Key Words: Industrial waste, Plastic Waste, Road Construction, Waste materials.

1.INTRODUCTION

Rapid industrialization, population growth, and increased consumer activities have led to an alarming rise in both industrial waste and plastic waste across the world (Agarwal et al., 2020). These wastes—many of which are non-biodegradable—pose severe environmental hazards including groundwater contamination, land degradation, soil pollution, and toxic emissions resulting from open burning (Verma, 2016). The improper disposal of these materials contributes to resource depletion and the expansion of landfill areas, making waste management a major global challenge (Choudhary et al., 2019). The road construction sector consumes large quantities of natural aggregates and bitumen, which has created an urgent need to identify sustainable alternative materials capable of reducing environmental impacts while maintaining engineering performance (Khan & Sharma, 2021). Researchers have found that plastic waste and industrial by-products can serve as effective partial or full replacements for conventional pavement materials in both flexible and rigid pavements (Patel & Lodha, 2022). Countries including India, Japan, and several European nations have already implemented waste-modified bituminous pavements, demonstrating improvements in load-bearing capacity, fatigue resistance, and service life (Singh & Mishra, 2018). This review consolidates major findings from existing research, summarizes experimental methodologies, evaluates the performance of waste-integrated pavement systems, and identifies future research directions to enhance sustainability in road construction (Agarwal et al., 2020).

2. LITERATURE REVIEW

2.1 Plastic Waste Modified Bitumen

Researchers have extensively examined the use of Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), polypropylene, and polyethylene terephthalate (PET) as bitumen modifiers in asphalt mixes (Verma, 2016). Studies consistently report that shredded plastic waste melts at temperatures around 170–180°C and adheres uniformly to heated aggregates, improving bonding with bitumen (Agarwal et al., 2020). This coating mechanism increases Marshall Stability values, enhances rutting resistance, and improves water resistance in asphalt pavements (Patel & Lodha, 2022). Field trials from several countries demonstrate that plastic-modified roads can last up to twice as long as conventional pavements and require less maintenance over their service life (Khan & Sharma, 2021).

2.2 Industrial Waste as Aggregates or Fillers

Industrial by-products such as fly ash, blast furnace slag, steel slag, quarry dust, and demolition waste have been successfully incorporated into various pavement layers (Choudhary et al., 2019). Fly ash improves subgrade performance due to its pozzolanic reactivity and ability to reduce swelling in clay soils (Agarwal et al., 2020). Blast furnace slag exhibits high durability and compressive strength, making it suitable for base and sub-base layers (Khan & Sharma, 2021). Steel slag is valued for its angular shape and high density, which enhance stiffness and skid resistance in flexible pavements (Singh & Mishra, 2018). Quarry dust improves mechanical interlocking due to its fine texture, while recycled construction debris provides a cost-effective alternative to natural aggregates (Verma, 2016). Studies consistently demonstrate that integrating industrial waste improves bearing capacity, durability, and moisture resistance in pavement materials (Patel & Lodha, 2022).

2.3 Combined Use of Industrial and Plastic Waste

Recent research highlights synergistic effects when both plastic waste and industrial by-products are used together in pavement mixes (Choudhary et al., 2019). Plastic-coated aggregates combined with fly ash fillers have shown improved stability, reduced bitumen consumption, and better workability (Agarwal et al., 2020). Studies also indicate that the combination of slag aggregates with plastic-modified bitumen enhances resistance

ISSN: 2583-6129
DOI: 10.55041/ISJEM05166

to thermal cracking and rutting (Khan & Sharma, 2021). These hybrid waste-based mixes offer promising outcomes for sustainable pavement design (Patel & Lodha, 2022).

3. METHODOLOGY

This review adopts a qualitative and systematic research methodology to synthesize findings from studies examining the use of industrial waste and plastic waste in road construction (Agarwal et al., 2020). Academic databases including ScienceDirect, Springer, Google Scholar, and IEEE Xplore were searched using keywords such as "plastic waste in road construction," "industrial waste pavement materials," "slag aggregates," and "sustainable asphalt technologies" to identify relevant literature (Patel & Lodha, 2022). Only peer-reviewed studies published between 2000 and 2024 that examined the mechanical, environmental, or economic performance of plastic or industrial waste in pavement materials were included to ensure reliability and analytical consistency (Choudhary et al., 2019). Studies lacking experimental data, research unrelated to pavement engineering, and waste utilization studies outside the context of civil engineering were excluded to maintain the scope of the review (Khan & Sharma, 2021). The literature was analyzed based on material characteristics, mix design techniques, mechanical performance indicators such as Marshall Stability and Indirect Tensile Strength, environmental and cost benefits, and available field performance data, providing a comprehensive understanding of technological developments and challenges in waste-based road construction (Singh & Mishra, 2018).

4. DISCUSSION

4.1 Engineering Performance

Plastic-modified bitumen significantly enhances the engineering properties of asphalt mixes by increasing stability, stiffness, and resistance to water absorption (Verma, 2016). Waste plastics also reduce sensitivity to temperature variations, thereby improving fatigue life and minimizing pothole formation in asphalt pavements (Agarwal et al., 2020). Industrial waste materials such as steel slag exhibit superior mechanical strength compared to natural aggregates, while fly ash improves subgrade behavior and reduces swelling in expansive soils (Singh & Mishra, 2018). Blast furnace slag and quarry dust further enhance the load-carrying capacity and overall durability of pavement layers (Choudhary et al., 2019).

4.2 Environmental Impact

The incorporation of industrial and plastic waste into pavement materials substantially reduces landfill accumulation and air pollution from open burning (Patel & Lodha, 2022). Waste-modified pavements also lower the consumption of natural aggregates and petroleum-based bitumen, thereby conserving natural resources (Agarwal et al., 2020). This approach aligns with circular economy principles and supports global Sustainable Development Goals related to climate action and responsible consumption (Khan & Sharma, 2021).

4.3 Economic Impact

Economic analyses show that using waste materials in road construction decreases material costs and reduces long-term maintenance due to improved pavement durability (Verma, 2016). Countries that have implemented plastic roads report notable cost savings over the pavement life cycle, primarily due to lower repair frequency (Choudhary et al., 2019). Furthermore, industrial waste materials are often readily available at low or no cost, offering significant financial advantages (Singh & Mishra, 2018).

4.4 Practical Limitations

Despite the benefits, waste-integrated pavement systems face challenges such as the need for effective segregation and cleaning of plastic waste prior to use (Agarwal et al., 2020). Excess plastic content can release toxic fumes if not processed within recommended limits (Verma, 2016). Industrial waste properties also vary significantly by region and manufacturing process, creating inconsistencies in performance outcomes (Khan & Sharma, 2021). Additionally, the absence of universal standards for waste-modified pavements limits widespread adoption across countries (Patel & Lodha, 2022).

5. RESEARCH GAPS

Although significant advancements have been made in waste-based pavement research, several gaps continue to hinder large-scale implementation (Choudhary et al., 2019). A major gap involves the lack of standardized mix design procedures that specify optimum plastic content, aggregate coating duration, and waste-to-bitumen ratios, which restricts the development of uniform specifications for industry-wide application (Agarwal et al., 2020). Another critical gap concerns the limited availability of long-term field performance data, as most studies rely on laboratory experiments without evaluating the behavior of waste-modified pavements under real traffic loads and diverse climatic conditions (Patel & Lodha, 2022). Environmental impact assessments are also insufficient, particularly regarding microplastic generation, emission of toxic compounds, and potential leaching from industrial waste materials such as slag (Khan & Sharma, 2021). Furthermore, the optimization of hybrid mixes combining multiple waste materials remains underexplored, creating opportunities for future studies to determine the most effective waste combinations for different pavement layers (Singh & Mishra, 2018). Finally, the scalability of waste-based road construction in rural and low-income regions requires additional research on affordability, community awareness, and logistical challenges to support widespread adoption (Verma, 2016).

6. CONCLUSION

The integration of industrial waste and plastic waste into road construction presents a sustainable, economically beneficial, and technically feasible solution for modern infrastructure development (Agarwal et al., 2020). Waste-modified pavements exhibit improved mechanical strength, enhanced durability, reduced maintenance costs, and lower environmental impact (Patel & Lodha, 2022). Although research findings support the effectiveness of waste-based materials in asphalt and subgrade applications, challenges related to standardization, environmental risks, and long-term field validation must be addressed to achieve global acceptance (Singh & Mishra, 2018). Future studies focusing on guidelines, environmental evaluations, material optimization, and field-scale implementation will strengthen the adoption of environmentally friendly pavement technologies worldwide (Choudhary et al., 2019).

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ACKNOWLEDGEMENT

We express our sincere gratitude **to** Dr. D. Y. Patil Pratishthan's College of Engineering, Salokhenagar, Kolhapur, Maharashtra, India**,** for providing the necessary resources, academic support, and conducive environment required for the successful completion of this project. We are deeply thankful to our respected faculty members and project guides for their constant guidance, valuable insights, and encouragement throughout the research work. Their expertise and constructive suggestions greatly contributed to the quality and outcome of this project.

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