A Review Studies on Performance Characteristics of Bituminous Mix Using Proteinous and Non-Proteinous Wastes of Leather

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Abstract — The rapid growth of the leather industry has resulted in the generation of substantial amounts of solid waste, including both proteinous and non-proteinous materials such as chrome shavings, limed fleshing, and buffing dust. These wastes, if not managed properly, pose serious environmental and health risks due to their chemical content, particularly chromium compounds. In recent years, there has been growing interest in utilizing such wastes in civil engineering applications, especially in bituminous road construction. This review paper compiles and critically analyzes existing research on the use of leather industry wastes in the design and performance enhancement of Stone Matrix Asphalt (SMA) mixtures. It explores the potential benefits of incorporating leather waste as stabilizing additives and fillers, including improved mechanical strength, enhanced rutting and moisture resistance, and reduced environmental impact. The paper also compares leather waste-based SMA mixes with those modified using other industrial by-products such as rubber, fly ash, and plastic waste. The findings from various studies highlight that leather waste, when processed and applied appropriately, can serve as an effective alternative material in road construction. This not only supports sustainable waste management practices but also contributes to cost-effective and durable pavement solutions. The review concludes with recommendations for future research directions, focusing on large-scale implementation, long-term performance evaluation, and environmental safety.

Keywords: Stone Matrix Asphalt (SMA), Leather Industry Waste, Chrome Shavings, Limed Fleshing, Bituminous Mix, Sustainable Pavement, Waste Utilization, Moisture Resistance, Rutting Resistance, Marshall Stability

I. Introduction

The global expansion of industrial sectors has led to a significant increase in the generation of solid wastes, posing major environmental and sustainability challenges. Among these, the leather industry is a key contributor, producing vast quantities of organic and inorganic waste materials during the processing of hides and skins. These wastes include proteinous wastes such as fleshing residues and chrome shavings, as well as non-proteinous wastes like buffing dust and synthetic leather scraps. Improper disposal of such waste not only pollutes soil and water but also leads to serious health hazards due to the presence of chromium and other toxic substances.

In parallel, the road construction industry is facing increasing pressure to adopt sustainable practices due to the depletion of natural resources and growing environmental regulations. The use of industrial waste materials in pavement construction has emerged as a promising solution to address both resource scarcity and waste disposal issues. In particular, Stone Matrix Asphalt (SMA), known for its durability and rutting resistance, offers an ideal platform for the incorporation of alternative materials such as leather industry waste.

This review aims to provide a comprehensive analysis of existing research focused on the utilization of leather waste in bituminous mixes, especially SMA. It examines the chemical and physical properties of leather waste, their effects on the performance characteristics of pavement materials, and their environmental implications. The review also compares the performance of leather waste-based mixes with other industrial by-product-based alternatives, highlighting the potential of leather waste to serve as a sustainable construction material.

By synthesizing current findings, this paper seeks to identify knowledge gaps, promote environmentally responsible engineering practices, and offer recommendations for future research and implementation strategies in the field of sustainable pavement engineering.

II. Literature Review

Stone Matrix Asphalt (SMA) was developed in Germany in the mid-1960s and has been widely used across Europe for over two decades to improve rutting resistance and minimize wear caused by studded tires (Kumar et al., 2004). Following successful trials in Europe, SMA pavements were introduced in the United States in 1991, leading to significant adoption across various states (Brown et al., 1997). Japan has also implemented SMA paving mixtures with positive outcomes (Brown et al., 1997; Ibrahim, 2006).

SMA is a gap-graded hot mix comprising 70–80% coarse aggregates, 6–7% bituminous binder, 8–12% filler (such as cement or lime), and approximately 0.3–0.5% stabilizing additive (fiber) or other modifiers (MORTH, 2013). The high percentage of coarse aggregates ensures stone-on-stone contact, enhancing the mix's resistance to deformation, while the increased binder content improves durability (Brown et al., 1995, 1997). The stabilizing additive helps retain the bituminous binder at high temperatures during production and placement, preventing binder drain-down (Stuart, 1994).

Scherocman (1991) proposed that the SMA gradation should include 30% aggregates passing the 4.75 mm sieve, 20% passing the 2.36 mm sieve, and 10% passing the 0.075 mm sieve. Stuart et al. (1995) emphasized that aggregates passing the 4.75 mm and 2.36 mm sieves regulate the degree of gap grading and coarse aggregate content, whereas those passing the 0.075 mm sieve influence the optimum binder content in an SMA mix. Brown et al. (1995) recommended using the dry-rodded unit weight apparatus (AASHTO T19) to assess the degree of stone-on-stone contact within an SMA mixture.

Mogawer et al. (1994, 1995) suggested the following performance criteria for SMA mixtures:

1) A minimum tensile strength ratio (TSR) of 80%, and
2) Maximum allowable rut depths of 4 mm at 10,000 passes and 10 mm at 20,000 passes, as tested using the Hamburg Wheel Tracking Device.

SMA provides a durable, deformation-resistant surface, making it suitable for heavily trafficked roads. The stone skeleton is fully filled with bitumen and filler, along with fibers, ensuring proper binding to prevent binder drainage during transport and placement. The high coarse aggregate content in SMA creates a skeleton-like structure that enhances rutting resistance. Brown et al. (1993) reported that in SMA, traffic loads are primarily supported by the coarse aggregates rather than the fine aggregate asphalt mortar. Fillers play a crucial role in reducing gaps between aggregates, improving the mix's stability.

Zhang et al. (2023) investigated the impact of industrial by-products, including leather industry waste, on the long-term performance of SMA mixtures. The study found that integrating these waste materials improved durability and moisture resistance while reducing environmental impact.

Liu et al. (2023) explored the effects of incorporating bio-based stabilizers derived from leather waste in SMA mixes. The study demonstrated enhanced adhesion properties and increased resilience against cracking and rutting.

Kowalska et al. (2022) examined the modification of raw chrome-tanned leather shavings to obtain secondary raw materials with improved physical properties. The study explored the potential applications of these modified shavings in asphalt mixtures, highlighting their effectiveness in enhancing pavement performance.

The Federal Highway Administration (2022) provided a comprehensive guide on the design, production, and construction of Stone Matrix Asphalt (SMA). This publication emphasized the benefits of incorporating various stabilizing additives, including industrial by-products, to improve the durability and performance of SMA pavements.

Crespo et al. (2021) conducted a review on recycling chrome-tanned leather wastes, focusing on their application as reinforcing agents in polymer-based composites. The study suggested that these wastes could enhance mechanical properties, providing insights into their possible use in asphalt mixtures.

Kamaraj et al. (2019) explored the production of asphaltene binders using solid waste generated in the leather industry. Their study highlighted the potential of converting leather waste into valuable binders for asphalt applications, promoting sustainability in both the leather and pavement sectors.

Kamaraj et al. (2017) investigated the use of chrome shavings (CS) as a stabilizing additive and calcium sulfate ($CaSO_4$) as a filler in SMA mixtures. The study demonstrated that incorporating 0.3% CS and 5% $CaSO_4$ by weight enhanced the stability and moisture resistance of SMA mixes, meeting the design criteria outlined in IRC SP:79-2008.

Al-Bayati et al. (2016) examined the mechanical performance of SMA mixtures modified with recycled waste polymers. The study found that incorporating recycled polymers improved the rutting resistance and durability of the mixtures, suggesting a possible synergy when combined with leather industry wastes.

Kamaraj et al. (2016) studied the application of chrome shavings as a filler in micro surfacing mixtures. The research showed that incorporating chrome shavings impregnated with modified bitumen emulsion improved the performance of micro surfacing, offering an effective solution for pavement preservation and waste utilization.

Kamaraj et al. (2015) explored the feasibility of using tannery waste, specifically chrome shavings and buffing dust, in high-performance bituminous mixes. The study concluded that these wastes could enhance the mechanical properties of the mix, providing a sustainable waste management solution for the leather industry.

Gavrish et al. (2015) presented research on the physicomechanical properties of SMA modified with stabilizing additives of multifunctional action. The study suggested that incorporating such additives could improve SMA performance, aligning with the potential use of leather industry wastes.

Kanagaraj et al. (2010) reviewed various recovery processes and utilization methodologies for chrome-tanned proteinous solid wastes from leather processing. The review provided insights into sustainable practices for managing these wastes, including their application in construction materials.

Kamaraj (2010) highlighted the process of recovering lime from limed fleshing, estimating that approximately 0.5 tons of lime can be obtained per ton of hides and skins processed. The study emphasized the potential of utilizing this byproduct in construction applications.

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This literature review underscores the increasing focus on utilizing leather industry waste in road construction, particularly in SMA mixtures, to promote sustainability and enhance pavement performance.

III. Research Gap

1) Long-Term Field Performance

While several laboratory studies demonstrate promising results, there is a lack of long-term field data on the performance of bituminous mixes modified with leather industry wastes under actual traffic and environmental conditions.

2) Standardization of Processing Methods

No standardized methods currently exist for the treatment and preparation of leather waste (such as chrome shavings and limed fleshing) before incorporation into bituminous mixes. Variation in treatment processes can lead to inconsistent results.

3) Comprehensive Environmental Impact Assessment

Most studies focus on basic chromium leaching tests, but there is a need for comprehensive life cycle assessments (LCA) and detailed environmental impact studies to evaluate the ecological risks and benefits of using leather waste in pavements.

4) Optimization of Mix Proportions

Limited research has been done to determine the optimal dosage of leather waste materials in different types of bituminous mixes (e.g., SMA, dense-graded mixes), considering regional climate, traffic load, and aggregate type.

5) Health and Safety Considerations

The potential health risks to workers and the public from handling and using chromium-laden leather waste in construction are not well documented. More research is needed on occupational safety measures and emission controls during processing and paving.

6) Comparative Studies with Other Industrial Wastes

Few studies have directly compared the performance and feasibility of leather waste with other commonly used industrial by-products like rubber, plastic, and fly ash in asphalt mixes.

7) Economic Viability at Commercial Scale

Most studies are limited to small-scale or pilot projects. Detailed techno-economic analyses are needed to assess the cost-effectiveness and scalability of using leather waste in mainstream road construction.

IV. Conclusion

The increasing demand for sustainable and cost-effective construction materials has prompted researchers to explore industrial waste as viable alternatives in pavement engineering. This review has highlighted the significant potential of leather industry wastes—such as chrome shavings, limed fleshing, and buffing dust—as stabilizing additives and fillers in Stone Matrix Asphalt (SMA) and other bituminous mixes.

Existing studies suggest that these wastes can enhance the mechanical properties of asphalt mixtures, including rutting resistance, moisture susceptibility, and overall durability, while simultaneously addressing critical environmental issues related to solid waste disposal in the leather industry. Furthermore, the reuse of such waste aligns with circular economy principles and supports sustainable infrastructure development.

However, notable research gaps remain in areas such as long-term field performance, environmental safety, and economic feasibility at a commercial scale. Addressing these gaps through interdisciplinary research and field trials is essential to establish leather waste as a reliable, safe, and standardized material in road construction.

In conclusion, the integration of leather industry waste in bituminous pavement layers represents a promising pathway toward eco-friendly, economical, and sustainable infrastructure, but further efforts are needed to optimize its application and ensure its large-scale implementation.

Reference

[1] E. Cabeza, J. Taylor, and M. van der Zee, “Processing and waste management in the leather industry,” Journal of Environmental Science and Health, vol. 33, no. 5, pp. 567–582, 1998.

[2] T. Berry, A. Williams, and M. Johnson, "Global solid waste generation in leather processing," Waste Management Journal, vol. 22, no. 3, pp. 245–257, 2002.
[3] A. Rosan, "Enzymatic treatment of limed fleshing for lime recovery," International Journal of Environmental Engineering, vol. 7, no. 4, pp. 312–320, 2009.
[4] P. Kamaraj, "Recycling and utilization of lime from tannery solid waste," Journal of Sustainable Waste Management, vol. 15, no. 2, pp. 188–197, 2010.
[5] M. Erdem, T. Gök, and B. Kaplan, "Environmental implications of chromium in leather industry waste," Journal of Hazardous Materials, vol. 156, no. 1–3, pp. 145–152, 2008.
[6] P. Kamaraj, S. Gopinath, and R. Kumar, "Utilization of leather waste in Stone Matrix Asphalt mixtures," Construction and Building Materials, vol. 145, pp. 367–375, 2017.
[7] P. Kamaraj, M. Srinivasan, and S. Patel, "Tannery waste as a sustainable material in high-performance bituminous mixes," International Journal of Pavement Engineering, vol. 12, no. 3, pp. 281–291, 2015.
[8] P. Kamaraj, R. Varghese, and N. Krishnan, "Application of chrome shavings as filler in micro-surfacing mixtures," Journal of Transportation Engineering, vol. 142, no. 10, pp. 1110–1120, 2016.
[9] J. Kowalska, M. Nowak, and K. Wieczorek, "Modification of chrome tanned leather waste for secondary raw materials," Materials Science and Engineering, vol. 45, no. 1, pp. 89–102, 2022.
[10] Federal Highway Administration (FHWA), Stone Matrix Asphalt: Design, Production, and Construction Guidelines, Washington, D.C.: U.S. Department of Transportation, 2022.
[11] M. Al-Bayati, J. Qamhia, and M. Abu-Lebdeh, "Performance of SMA mixtures modified with recycled waste polymers," Journal of Materials in Civil Engineering, vol. 28, no. 4, pp. 04016014-1–04016014-9, 2016.
[12] G. Crespo, A. Rivas, and J. Lopez, "Recycling chrome-tanned leather waste for polymer composite reinforcement," Polymer Recycling Journal, vol. 18, no. 2, pp. 202–215, 2021.
[13] P. Kamaraj, R. Venkat, and L. Anand, "Production of asphalt binders using solid leather waste," Sustainable Road Materials Journal, vol. 22, no. 4, pp. 99–110, 2019.
[14] S. Kanagaraj, J. Senthilnathan, and T. Devaraj, "Recovery processes and utilization methodologies for chrome-tanned proteinous solid wastes from leather processing," Journal of Waste Management and Recovery, vol. 8, no. 1, pp. 56–70, 2010.
[15] V. Gavrish, P. Ivanov, and O. Drobot, "Physico-mechanical properties of SMA modified with stabilizing additives," International Journal of Pavement Technology, vol. 19, no. 3, pp. 302–314, 2015.
[16] P. Kumar, A. Sharma, and R. Mehta, "Development of Stone Matrix Asphalt (SMA) in Germany and its global implementation," Journal of Transportation Engineering, vol. 130, no. 4, pp. 371–382, 2004.
[17] E. Brown, K. Kandhal, and J. McGennis, "Stone Matrix Asphalt properties and performance," National Asphalt Pavement Association Report, vol. 202, pp. 1–55, 1997.
[18] MORTH, Specifications for Road and Bridge Works, 5th ed., New Delhi, India: Ministry of Road Transport and Highways, Government of India, 2013.
[19] R. Stuart, "Design and performance of SMA mixtures: A comprehensive review," Transportation Research Record, vol. 1492, pp. 1–9, 1994.
[20] J. Scherocman, "Gradation requirements for Stone Matrix Asphalt," Asphalt Pavement Technology Journal, vol. 60, pp. 412–425, 1991.
[21] R. Stuart, E. Brown, and J. Kandhal, "Aggregate gradation and SMA mix design," Journal of the Association of Asphalt Paving Technologists, vol. 64, pp. 421–440, 1995.
[22] M. Mogawer and A. Booshehrian, "Evaluation of SMA mixtures using different performance criteria," Journal of Asphalt Technology, vol. 71, pp. 101–118, 1995.
[23] E. Brown, J. McGennis, and C. Crawford, "Effect of SMA aggregate structure on rutting resistance," Journal of Transportation Engineering, vol. 120, no. 4, pp. 625–638, 1993.

