



Research Progress on the Utilization of Solid Waste in Asphalt and Asphalt Mixtures

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

In the field of sustainable civil engineering, the application of solid waste in asphalt and asphalt mixture has become an important research direction. Industrial wastes such as rubber, plastic, red mud, coal gangue and steel slag can be recycled as modifiers to optimize asphalt performance, improve the road performance of the mixture, reduce production costs, and have both economic and social benefits. At present, domestic and foreign scholars have done a lot of research on solid waste modified asphalt and asphalt mixture, and achieved some results. It has important application value and broad development prospects in the engineering field, and has positive significance for environmental protection, sustainable development and urbanization. Although the existing research in this book lacks some unique data and novel insights, it systematically summarizes the latest progress and provides a valuable reference for scholars who are not familiar with this field.

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1. INTRODUCTION

Transportation, whether evoking the legacy of the ancient Silk Road, the maritime exploration of the Age of Navigation, or the interconnected networks of modern infrastructure, has consistently served as a catalyst for economic integration and cross-cultural exchange. As a critical component of transportation systems, highway construction plays a pivotal role in establishing efficient and comprehensive transport networks. Within the domain of road construction and maintenance, asphalt mixtures constitute the predominant paving material due to their superior ride comfort, noise reduction, rapid construction, and ease of maintenance, making them the preferred choice for high-quality pavement (Yu et al., 2020). However, the escalating production of asphalt and asphalt mixtures has led to a surge in demand for conventional materials such as bitumen, aggregates, and mineral fillers. This trend exacerbates the depletion of natural stone resources and contributes to environmental degradation. In response, the incorporation of solid waste materials—either as asphalt modifiers or as substitutes for aggregates and fillers in asphalt mixtures—has emerged as a promising solution. This approach not only enhances the performance characteristics of asphalt and its mixtures but also facilitates the recycling of solid waste, thereby improving resource utilization efficiency and mitigating environmental pollution. The academic community has conducted extensive research on the potential applications of solid waste in road construction materials, with particular emphasis on its effects on the performance of asphalt-based materials. To date, industrial by-products such as steel slag, coal slag, and fly ash have been successfully integrated into asphalt mixture production. The scientifically optimized utilization of these waste materials in pavement engineering presents a viable pathway for industrial waste recycling. Such practices hold significant value in advancing environmental conservation and fostering sustainable urbanization.

2. RESEARCH PROGRESS OF SOLID WASTE IN ASPHALT

The recycling of waste tires remains a significant global environmental challenge. In many developing countries, substantial quantities of waste tires continue to be disposed of through

unsustainable methods, including open-air storage, incineration, and landfilling. Through mechanical crushing and chemical processing, waste tires can be transformed into rubber powder or particles of varying morphologies and particle sizes, which demonstrate excellent potential for asphalt modification. Rubber-modified asphalt has emerged as an environmentally sustainable pavement material, exhibiting superior performance characteristics including enhanced high-temperature stability, improved low-temperature flexibility, and increased resistance to aging, fatigue, and water damage. These properties make it particularly suitable for application in stress-absorbing layers and surface courses of pavement structures. Zhang et al (2024). Adopted the design concept of full-high-content rubber asphalt pavement structure, and designed three kinds of dense-graded high-content rubber asphalt mixtures ARHM-13, ARHM-20, and ARHM-25 for different structural layers. The road performance of high content rubber asphalt mixture in high and low temperature environment was analyzed and evaluated by dynamic stability, low temperature bending failure strain, freeze-thaw splitting strength, residual stability, four-point bending fatigue test and constrained specimen temperature stress test. The results show that; the high-volume rubber asphalt mixture with 30 % rubber powder content has good high temperature, fatigue performance and excellent low temperature performance.

Waste plastic is a common solid waste, commonly used waste plastics are PE, PP, PVC, PET, EPS, PA, ABS. Waste plastics can be used as modifiers for asphalt alone or in combination with other materials, which can improve the high and temperature stability, fatigue resistance and water damage resistance of asphalt. Punith V S (2007) recycled polyethylene was extracted from the low-density PE handbag collected from domestic waste, and it was used as a modifier to prepare modified asphalt and used in asphalt mixture. Through its performance test, it was found that compared with the traditional mixture, the performance of PE modified asphalt mixture was better. Adding PE to the asphalt mixture can reduce the possibility of rutting and temperature sensitivity. It is recommended that the 5 % weight of asphalt PE content be used to improve the performance of the asphalt concrete mixture. Wang Yong et al (Wang et al., 2022). Prepared waste PE/PPA composite modified asphalt with waste PE plastic and polyphosphoric acid (PPA)

as modifiers. The compatibility, rheological properties, adhesion properties and water resistance of waste PE modified asphalt with different contents of PPA were studied. The results show that PPA can promote the uniform dispersion of waste PE in asphalt and improve the compatibility between waste PE and asphalt. With the increase of PPA content, the penetration and ductility of composite modified asphalt decreased, and the softening point and viscosity increased significantly. The dynamic shear rheological test proves that PPA can improve the high temperature elastic recovery rate and low temperature fatigue resistance of composite modified asphalt. With the increase of PPA content, the pull-out strength and immersion resistance of composite modified asphalt gradually increased.

As a kind of solid waste, red mud has the characteristics of stable chemical composition, easy breakage and rich micropores, and has the potential to replace limestone powder for asphalt mixture production. However, at present, the world is facing the problem of large accumulation of red mud and low utilization rate. How to make red mud large-scale and reduce the use of red mud is an urgent problem to be solved. Fu et al (2020). used red mud as a modifier to study its modification mechanism from a microscopic point of view. The results showed that after mixing red mud, the penetration index and 15°C ductility of asphalt decreased, and the softening point increased, thereby improving the temperature sensitivity and high temperature stability of asphalt. The energy of asphalt changing with temperature was analyzed by molecular simulation technology. It was found that the main component of hematite in red mud was adsorbed most in asphalt, followed by asphaltene and colloid, but the adsorption capacity of colloid was the highest. Molecular dynamics simulation shows that after adding base asphalt, red mud can form a uniform and stable blending system with base asphalt. Al_2O_3 in red mud is the main component to improve the adhesion between red mud and asphalt interface. Professor Bao Huiming et al (2019). analyzed the effect of red mud content on the temperature sensitivity of asphalt through the viscosity-temperature index under different temperature scales, and studied the compatibility of red mud modified asphalt under different storage time through segregation test. The microscopic state of red mud modified asphalt was characterized by scanning electron microscopy. The results show that when the temperature is higher than 135°C, the influence

of shear rate on the viscosity of modified asphalt gradually decreases. The viscosity of modified asphalt with 5% red mud content is the largest and the temperature sensitivity is the smallest. When the content of red mud is 3%, it can reduce the viscosity to a certain extent. The main factors affecting the compatibility of red mud modified asphalt are red mud content, heat storage time and heat treatment conditions. With the increase of red mud content and the extension of storage time, the storage stability of red mud modified asphalt becomes worse, that is, the compatibility becomes worse, and the red mud calcined at high temperature is more compatible with asphalt than the original red mud.

In summary, the incorporation of solid waste materials as modifiers in asphalt preparation demonstrates significant potential for enhancing the performance characteristics of asphalt mortar. This approach not only optimizes the material properties but also contributes to sustainable development by improving solid waste utilization efficiency and mitigating environmental pollution.

3. RESEARCH PROGRESS OF SOLID WASTE IN ASPHALT MIXTURE

Coal gangue, a byproduct generated during coal mining and washing processes, represents a significant category of industrial solid waste. This black-gray sedimentary rock, characterized by lower carbon content and greater hardness than coal, forms as an integral part of coal seams. It encompasses three primary types: tunneling gangue from roadway excavation, extracted gangue from roof, floor, and interlayer strata during mining operations, and washing gangue separated during coal preparation. Chemically, coal gangue consists predominantly of Al_2O_3 and SiO_2 , with substantial concentrations of Fe_2O_3 , CaO , and MgO , along with minor constituents including Na_2O , K_2O , P_2O_5 , SO_3 , and trace rare earth elements (e.g., gallium, vanadium, titanium, cobalt). When processed into fine powder and incorporated into asphalt mixtures as a partial replacement for conventional limestone filler, coal gangue demonstrates notable engineering benefits. Experimental studies have confirmed its capacity to enhance mixture stability and elastic modulus while significantly improving resistance to freeze-thaw cycle damage—a critical performance parameter in pavement engineering. Wu et al (2022). also used different substitution amounts of coal gangue powder to replace mineral powder to study the variation of coal gangue powder under different freeze-thaw

cycles. It was found that the content of coal gangue powder had a significant effect on the asphalt mixture, and the best substitution amount was 50%. The addition of coal gangue powder significantly reduced the damage of freeze-thaw cycles to the mixture. Through three-point bending test and microwave heating test, Lu and Li et al (2023; 2022). Found that the combination of coal gangue and functional aggregate promoted the self-healing of micro-cracks at the interface between aggregate and asphalt, and the crack resistance and healing effect were significantly improved. Zhang et al (2023). Combined coal gangue into powder and basalt aggregate to evaluate the adhesion, mechanical properties, low temperature crack resistance, water stability, microwave heating capacity and self-healing efficiency of coal gangue asphalt mixture. It was found that the addition of coal gangue could improve the microwave heating speed, and also showed significant advantages in water stability and self-healing, further improving the utilization rate of coal gangue.

As a collection of various impurities produced in the steelmaking process, steel slag belongs to industrial solid waste, and its output is about 15 % ~ 20 % of the crude steel output. According to the steelmaking process and slag forming process, steel slag can be divided into converter steel slag, arc slag and ladle refining slag. At present, most researchers at home and abroad use it as stone instead of natural stone for secondary recycling and application in asphalt mixture (Li et al., 2022). Chen et al (2016). studied the asphalt mixture with alkaline oxygen furnace (BOF) steel slag as coarse aggregate, and found that adding steel slag to the asphalt mixture has a high resistance to permanent deformation and damage caused by moisture. Lu et al (Lu & Li, 2012). used full steel slag and partial steel slag instead of conventional gravel as aggregate to prepare AC-20 asphalt mixture. Through the analysis of its performance, the results show that the mixture is superior to the traditional gravel mixture in terms of high temperature stability, low temperature crack resistance and fatigue performance. Although its water stability is slightly inferior to that of gravel mixture, it still meets the requirements of relevant specifications. Hadi Goli et al (Lu & Li, 2012). used steel slag coarse aggregate in warm mix asphalt mixture. The water sensitivity of asphalt mixture was evaluated by Marshall stability ratio, elastic modulus ratio, tensile strength ratio and fracture energy ratio. The fatigue and rutting behavior of the mixture were evaluated by 4-

point beam fatigue and dynamic creep tests. The results show that the use of coarse aggregate in WMA mixture enhances the resistance of asphalt mixture to water damage and permanent deformation.

Fly ash is a powder-like fine particle discharged from a coal-fired boiler in a thermal power plant. It is usually a hollow porous spherical structure with a large specific surface area. At present, most researchers at home and abroad use it as a filler to replace natural stone in asphalt mixture. Zhang Baolong et al (Zhang et al., 2018). aimed at the interaction between fly ash and asphalt, with the help of surface modification technology, NaOH alkaline solution and KH550 coupling agent were used to treat four different sources of fly ash. The results show that the modified fly ash can reduce the elasticity of the green mortar, improve the anti-deformation ability of the green mortar, and improve the anti-rutting ability of the slurry. Jamshidi Ali et al (2018). added fly ash instead of filler to hot mix asphalt mixture and warm mix asphalt mixture respectively. The results show that the tensile strength of asphalt mixture containing fly ash not only meets the design standard, but also its tensile strength is higher than that of asphalt mixture containing cement filler. For warm mix asphalt mixture, the addition of fly ash increases the elastic modulus of asphalt mixture by 7.5%, which reduces the greenhouse gas emission in the manufacturing stage of raw materials.

Iron tailings are the waste after beneficiation and the main component of industrial solid waste. In recent years, a number of domestic and foreign studies have shown that iron tailings have a good application prospect in asphalt mixture as coarse aggregate or fine aggregate. Liu Mingyang et al (Liu et al., 2022). prepared iron tailings-steel slag aggregate micro-surfacing mixture. Through the test of its road performance, it was found that iron tailings and steel slag had a significant enhancement effect on the wear resistance, long-term skid resistance and rutting resistance of the micro-surfacing mixture. The incorporation of iron tailings will adversely affect the cohesion and water damage resistance of the mixture, but the incorporation of steel slag can effectively improve the problem of poor adhesion caused by iron tailings. Cao et al (2022). used iron tailings to replace coarse and fine aggregates. It was found that the iron tailings asphalt mixture had better high temperature performance, but its low temperature performance and water stability were relatively poor.

Waste glass is a kind of inorganic solid waste, and its main components are silica (SiO₂), sodium oxide (Na₂O), calcium oxide (CaO) and so on. It is found that the recycled glass asphalt mixture has the characteristics of low permeability, high friction coefficient and excellent reflective performance, and there is a high correlation between the reflective performance of glass asphalt concrete and the glass content, and the reflective performance is enhanced with the increase of the content. With the increase of road wear, the reflective intensity of glass asphalt pavement gradually becomes stronger.

In conclusion, extensive research has demonstrated the successful application of various industrial solid wastes as partial or complete substitutes for natural aggregates in asphalt mixtures. This approach represents an optimal solution for addressing solid waste pollution, offering multiple environmental and economic benefits. Specifically, it simultaneously resolves the challenges associated with massive waste accumulation while achieving significant energy conservation and reduced resource consumption. From an environmental perspective, this methodology not only contributes to ecological protection but also maximizes the practical value of solid wastes through expanded utilization pathways (Agrawal & Malviya, 2025; Ahmed et al., 2025; Solid Waste Management, 2017).

4. CONCLUSION

The utilization of processed solid wastes in asphalt modification has been shown to significantly improve its engineering properties. Various types of solid waste can effectively enhance asphalt's viscosity, rheological behavior, and durability while modifying its softening point characteristics. When used as replacements for conventional aggregates or fillers in asphalt mixtures, these materials substantially influence the composite's mechanical performance by improving key functional attributes such as high-temperature stability, low-temperature crack resistance, moisture susceptibility, fatigue life, and long-term durability. From an environmental perspective, this approach provides a sustainable solution to multiple challenges. It effectively addresses the issues of solid waste accumulation while simultaneously reducing the economic and ecological impacts associated with natural resource extraction. The methodology aligns with contemporary green development principles by promoting resource efficiency and

supporting circular economy models in construction practices. The integration of solid waste materials into asphalt technology represents a significant advancement in sustainable infrastructure development. By simultaneously optimizing material performance and addressing environmental concerns, this approach establishes a synergistic relationship between technological innovation, economic viability, and ecological conservation. The implementation of such sustainable practices in transportation infrastructure holds considerable potential for advancing environmentally responsible construction while maintaining engineering performance standards.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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