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USE OF RECYCLED MATERIALS IN PERMEABLE PAVEMENTS: SUSTAINABLE ADVANCES FOR URBAN INFRASTRUCTURE

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ABSTRACT

Rapid urbanization and environmental concerns related to soil impermeabilization have driven the development of sustainable solutions for urban infrastructure, such as permeable pavements. The use of recycled materials, such as recycled concrete aggregate (RCA), crushed bricks (CB), and reclaimed asphalt pavement (RAP), has proven to be a promising alternative for pavement construction, aligning with the concept of sponge cities. Recent studies show that, when properly treated and incorporated into different structural layers, these materials can provide effective solutions for rainwater management, reduce surface runoff, and contribute to aquifer recharge. In addition to contributing to urban sustainability, the use of CDW also promotes the circular economy by reducing dependence on natural resources and lowering carbon emissions. Research by Lei et al. (2020), Cai et al. (2020), and other studies show that using treatments such as silicone resin and lime, along with strict quality control of recycled materials, can improve the mechanical properties and water stability of pavements. Despite challenges like clogging and abrasion, the analyses indicate that these solutions are viable for both urban and rural pavements. The large-scale implementation of permeable pavements with recycled materials represents an innovative solution to urban drainage issues and construction waste management.

Keywords: Permeable pavements. Recycled materials. Circular economy. Recycled aggregates. Urban drainage.

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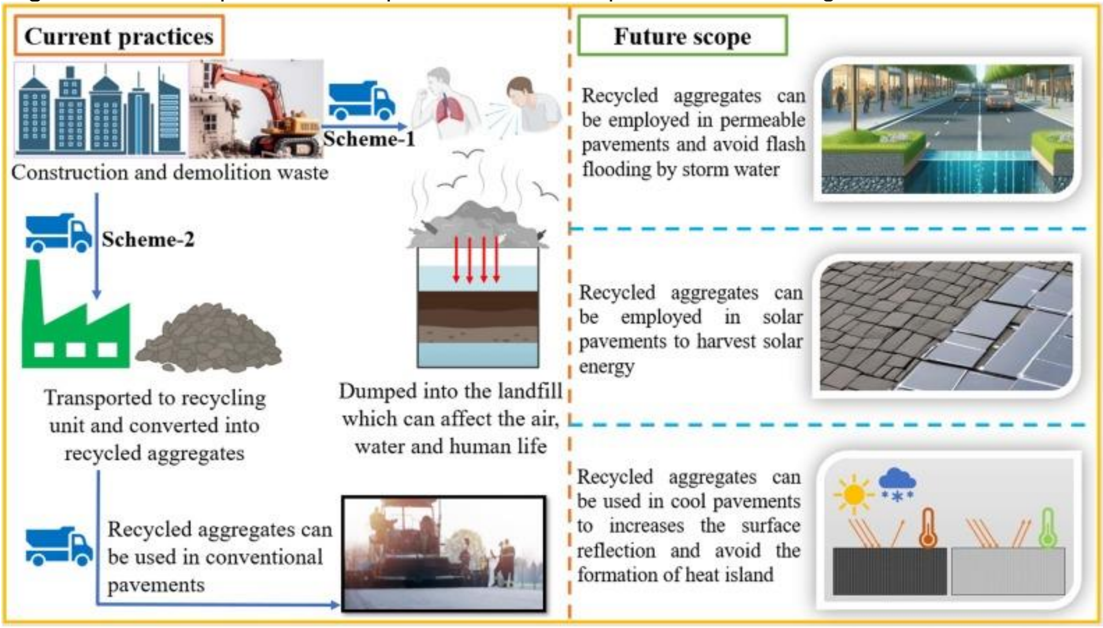
INTRODUCTION

The rapid urbanization and the environmental challenges associated with soil impermeabilization have fostered the development of sustainable solutions in urban infrastructure. In this context, permeable pavements have emerged as a promising alternative, as they facilitate the infiltration of rainwater into the soil, thereby reducing surface runoff and aiding in aquifer recharge. Utilizing recycled materials from demolition waste in the production of these pavements represents a key step towards promoting circular economy practices, while also minimizing the reliance on virgin raw materials.

Figure 1: Current practices and possible future scope in utilization of generated C&D wastes.



Source: Khan et al. (2024).

This case study focuses on the creation of a permeable pavement using recycled concrete aggregate (RCA), crushed brick (CB), and reclaimed asphalt pavement (RAP), incorporated into different structural layers. The materials were characterized in terms of grain size distribution, density, mechanical strength, hydraulic conductivity, and pollutant filtration capacity. Laboratory tests, including compaction, unconfined compressive strength, and permeability assessments, were conducted to evaluate their technical performance. Additionally, a field test section was constructed to validate the laboratory results, and monitored over a six-month period to assess infiltration capacity, clogging, and structural stability. The findings demonstrated that using 100% RCA as coarse aggregate provided the best balance between infiltration capacity and structural strength. Crushed brick, although offering higher water storage capacity, showed lower mechanical performance. The use of geotextiles as a filtering layer helped retain fine particles, reducing water contamination, though it required periodic maintenance to prevent clogging. Overall, the study affirms the practical viability of using recycled construction and demolition waste in permeable pavements, provided there is stringent material quality control and effective maintenance planning.

The research by Zhi et al. (2023) explored the development of cement-stabilized permeable road subgrade materials that incorporate construction and demolition waste as a partial replacement for natural aggregates. The goal was to enhance the value of construction waste by creating recycled materials with viable technical properties. The study examined properties such as compressive strength, water permeability, flexural strength, and compressive resilience modulus across various cementitious additive ratios. The results showed that with 30% recycled aggregates, the material achieved a compressive strength greater than 3.5 MPa after seven days and a permeability coefficient exceeding 3.5 mm/s, meeting China's road subgrade specifications. However, the presence of red bricks, old concrete, and ceramics in the recycled aggregates reduced both the mechanical properties and permeability. The addition of cementitious additives, however, significantly improved the material's structural performance by filling micropores in the interfacial transition zone.

Vieira et al. (2020) investigated the potential use of recycled aggregates (RA) from construction and demolition waste, combined with fly ash, in the production of pervious concrete as a sustainable alternative for pavements. This study aimed to mitigate the environmental impacts associated with raw material extraction and CDW disposal. The research involved two series of pervious concrete mixes—one with varying water-to-binder (w/b) ratios and another with a constant w/b ratio and 10% cement replacement by fly ash. The mixes were tested for compressive and flexural strength, permeability, infiltration rate, surface abrasion, clogging potential, and microstructural characteristics using scanning electron microscopy (SEM) and x-ray microtomography. The results showed that incorporating 10% fly ash with 75% recycled aggregate slightly increased the clogging tendency by 6% compared to the reference concrete. Furthermore, higher RA content led to increased clogging susceptibility and surface abrasion, with the 50% RA mix exhibiting the highest clogging tendency. Despite these challenges, the study found a strong correlation between the macrostructural performance and void content, suggesting that optimized mixes with RA and fly ash can maintain permeability while effectively promoting the reuse of waste materials.

Lei et al. (2020) explored the integration of recycled concrete aggregate (RCA) in permeable asphalt mixtures (PAMs) as a method to efficiently utilize construction and demolition waste. This approach aligns with the concept of building "sponge cities" and addresses the overexploitation of natural aggregate resources. The study investigated the use of modification treatments and hybrid fiber addition to enhance the performance of PAMs with RCA. The results indicated that substituting natural aggregates with RCA increased the optimum asphalt content (OAC) while reducing residual stability. Specifically, when the RCA ratio reached 100%, the OAC increased by 45%, but applying silicone resin reduced the OAC by 16.2%. The silicone resin treatment also improved water stability, bringing it to levels comparable with natural aggregates. Additionally, treatment with calcium hydroxide solution enhanced the mechanical strength of PAMs, surpassing that of mixtures with natural coarse aggregates. While cement slurry also improved the mechanical strength and water stability of PAMs, its effects were not as pronounced as those of silicone resin. The permeability of PAMs initially decreased with higher RCA content but later increased, suggesting that PAMs with RCA and modification treatments can be an effective pavement material that meets the criteria for concrete pavement applications.

Cai et al. (2020) examined the use of recycled concrete aggregates (RCA) and crushed bricks (CB) in pavement materials as an effective solution for waste management. Through material design optimization, the study demonstrated that RCA and CB could be incorporated into permeable concrete as a road base, in alignment with the principles of the "sponge city" concept. The research evaluated cement-treated permeable concrete containing RCA and CB, focusing on compressive strength, shrinkage, and water permeability. The results indicated that cement-treated permeable concrete with CB exhibited fast drying and low shrinkage, making it ideal for road base applications. Although CB reduced the concrete's strength slightly, it remained within acceptable limits according to existing specifications, and its permeability performance was satisfactory. The study recommended that concrete with 15% CB by weight (CB-15) be suitable for roads with moderate traffic, while CB-free concrete (CB-0) would be more appropriate for high-traffic areas. This research suggests a promising path for the large-scale use of RCA and CB, contributing to environmental protection and sustainable urban development.

The paper by Pourkhorshidi et al. (2020) focuses on the growing interest in using recycled materials, specifically construction and demolition waste aggregates (CDW), in the construction of pavements. Pavements, as a key component of transportation infrastructure, require substantial resources for their construction and maintenance. The study highlights that incorporating recycled materials into pavements provides a sustainable solution by reducing the carbon footprint of the construction sector, conserving natural resources, reducing harmful emissions, and minimizing overall construction and maintenance costs. The paper reviews various studies on the use of CDW aggregates in unbound pavement layers, comparing results from different engineering assessments. Several tests and evaluations are applied to ensure the quality and durability of pavements under varying traffic volumes, loads, and climatic conditions. While unbound recycled aggregates (RA) are primarily used in lower layers like subgrades, capping, sub-bases, and bases, the study suggests that in rural areas, these aggregates could also be utilized in bound layers, paving the way for novel surfacing applications.

Lastly, Beja, Motta, and Bernucci (2020) assessed the feasibility of using recycled construction and demolition waste (CDW) as an aggregate in pavements subjected to high-volume, heavy traffic. Laboratory tests were performed to measure the resilient modulus and permanent deformation of the material, while field tests measured pavement deflections and back-calculated resilient moduli. The study showed that stabilizing CDW with Portland cement or lime significantly enhanced the mechanical behavior of the aggregate, reducing the variability of mechanical responses. Both laboratory and field results indicated that the stiffness of CDW aggregates increased over time. The study concluded that CDW could be a viable alternative for subbase layers in pavements under heavy traffic, offering a sustainable solution for pavement construction.

The research on the use of recycled materials, especially construction and demolition waste (CDW), in permeable pavement construction reveals a significant advancement toward more sustainable urban solutions. The incorporation of recycled aggregates, such as recycled concrete aggregate (RCA), crushed bricks (CB), and reclaimed asphalt pavement (RAP), not only contributes to reducing construction

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material waste but also offers effective solutions for rainwater management, helping to recharge aquifers and reduce surface runoff. The application of these materials, along with modification treatments like the use of silicone resin and lime, has proven to be an effective approach to improve mechanical strength and water stability, meeting the required criteria for urban and rural pavements.

Furthermore, the use of recycled materials promotes the circular economy by contributing to the preservation of natural resources and reducing the carbon footprint of the construction industry. Studies by Zhi et al. (2023) and Vieira et al. (2020) highlight that, despite challenges such as clogging and abrasion, it is possible to optimize permeable concrete mixes with recycled aggregates to achieve a good balance between technical performance and sustainability. The large-scale adoption of these recycled materials, in addition to providing a solution for construction waste management, can represent a significant step forward in the development of green infrastructure, preparing cities for future environmental challenges.

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