Preliminary Investigations on the Performance and Characterization of Municipal Wastewater Sludge-Derived Biochar–Plastic Composites: A Resource-Oriented Solution to Sludge and Plastic Waste

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Abstract: Plastic waste has emerged as a pressing global concern, with a significant portion of it being discarded into the environment. Concurrently, wastewater sludge has also become an environmental threat due to the potential contaminants in it. In response, in this study, we took a novel approach that focused on the development of a sustainable composite matrix made from sludge-derived biochar and plastic. The physical, mechanical, and mineralogical properties of plastic–biochar (PB) composite matrices, including water absorption capacity (WAC), bulk density, wet transverse strength, and thermal conductivity, were assessed. The WAC increased with a higher biochar content in the matrix, ranging from 1.39% to 2.40%. The bulk density increased from 0.66 to 0.94 g/cc with increasing biochar content. The wet transverse strength exceeded the minimum requirement of 3 MPa in all tested samples, demonstrating the matrices' robustness. The thermal conductivity values ranged from 0.2 to 0.3 W/m · K, indicating the matrices' potential as insulating materials. Fourier-transform infrared (FTIR) spectroscopy confirmed the presence of the biochar and its bonding with polyethylene terephthalate (PET) in the composite matrices. X-ray diffraction (XRD) analysis revealed shifts in the peak patterns with varying biochar content, demonstrating alterations in the crystallinity. Field emission scanning electron microscopy (FE-SEM) micrographs illustrated the interactions between the biochar and the PET, highlighting their distinctive attributes. A cost analysis showed that the PB composite matrices were cheaper than traditional cement concrete tiles. Finally, the potential of PB composite matrices to sequester carbon was assessed, which could contribute to reducing the carbon footprint of construction. This study demonstrated the potential of BP composite matrices as sustainable and cost-effective materials with satisfactory physical properties and the ability to reduce environmental impact. **DOI:** 10.1061/JHTRBP.HZENG-1316.

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Introduction

Rapid population growth and intense urban development have led to a significant increase in the production of sewage sludge. According to a report released by the Central Pollution Control Board (CPCB) in March 2021, India's expected sewage production from urban areas is 72,368 million L/day (MLD), with a total daily sewage treatment capacity of 31,841 MLD. As a result, the disposal of sewage sludge is of the utmost importance. Sewage sludge can be converted into biochar with the help of pyrolysis. In the process of pyrolysis, materials are burned at a high temperature without, or in the presence of a limited supply of, oxygen (Bashir et al. 2022). This is a versatile and environmentally friendly method for converting biomass into biochar, offering benefits such as carbon sequestration, soil improvement, waste utilization, and energy production. The major outcome is the formation of a solid carbon structure (biochar), which traps the carbon from organic matter in solid form and stops it from breaking down and releasing methane (CH_4), carbon monoxide or carbon dioxide (CO_2). As a result, the amount of CO_2 that enters the atmosphere is decreased (Zhang et al. 2022). Due to its potential to provide additional advantages in the treatment of sewage sludge, biochar made from sewage sludge has recently been receiving attention (Lu et al. 2013).

Biochar has emerged as a subject of significant scholarly and industrial interest due to its efficacy as a soil amendment and its capacity to mitigate inorganic and organic pollutants. The nonedible nature and carbon composition of biochar position it as a strategic contributor to contemporary economic and social advancement, offering opportunities for waste reduction and the generation of valuable commodities (Das et al. 2015). A recent research frontier involves the exploration of biochar's integration into construction materials. The judicious application of biochar in the construction sector presents a promising avenue for substantial environmental gains, including the reduction of CO_2 emissions and the reclamation of waste materials (Zhang et al. 2022). Urbanization has fueled

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Carbon Sequestration Potential

Cement production is a significant source of carbon emissions, accounting for approximately 7% of global CO_2 emissions, with 1 t of production resulting in approximately 0.95 t of CO_2 emissions, according to Liu et al. (2020). Cement is used as a key ingredient in concrete, which is the most widely used building material in the world. To mitigate these emissions, we explored a potential solution by developing an alternative building material capable of replicating some of the indispensable properties of concrete while cutting down on carbon emissions, with the aim of replacing some of the concrete in some construction applications. The focus of the current study was limited to manufacturing a composite matrix in the form of a tile.

In the production of CCTs, M20-grade concrete is commonly employed, which incorporates aggregates with a maximum size of only 10 mm. For the manufacture of a 1-kg batch of this mixture, an approximate dry weight of 161 g of cement is utilized. During the manufacturing of this quantity of cement, around 152.95 g of CO_2 is released into the atmosphere. Contrastingly, the PB composite matrix can be employed to replace traditional CCTs while also potentially helping to sequester carbon. This is because biochar has greenhouse gas–reducing properties, offering net negative greenhouse gas emissions of about 870 kg CO_2 equivalent (CO_2-e)/t dry feedstock, of which 62%–66% is released from carbon capture and sequestration (CCS) by the biomass feedstock (Gupta and Kua 2017). This means that, in addition to reducing the carbon footprint of the manufacturing process, biochar acts as a carbon sink, implying that it has the ability to sequester carbon that would otherwise be released to the atmosphere.

The weight-based carbon content was determined to be 60% using a proximate analysis of the biochar. This finding was further corroborated by conducting a comprehensive carbon–hydrogen–nitrogen–sulfur (CHNS) analysis on the biochar sample. The data presented in Table 4 give the specific quantities of biochar utilized in the production of a PB composite. For the respective PET-to-biochar ratios of 90:10, 70:30, and 50:50, the corresponding amounts of biochar utilized in manufacturing 1 kg of PB composite were 100, 300, and 500 g. Considering a stability factor of fixed carbon assumed to be 0.5, this translates into the fixation of approximately 110, 330, and 550 g of CO_2-e/kg of manufactured tile. A clear distinction can be drawn between the CO_2 emissions generated during the manufacturing of CCTs and PB composite matrix tiles. With the former, approximately 152.96 kg of CO_2 is released per kilogram of tile manufactured. By contrast, an average of 330 g of CO_2 is sequestered during the production of PB composite matrix tiles. This indicates that the manufacturing process of PB composite matrices has the potential to reduce the overall carbon footprint in comparison to CCTs.

Conclusion

Our findings indicate the favorable potential of providing a cost-effective alternative to traditional concrete building materials. This can be achieved through the development of composite matrices made of biochar and PET. These materials are not only affordable, but they are also environmentally friendly and straightforward to manufacture. As a result, they present a viable and secure substitute for conventional concrete in construction applications. In this study, different ratios of biochar and PET were prepared to check the feasibility of the composite matrix as a construction tile. It was found that 50% of the binder plus 50% of the biochar made a suitable and workable composite matrix. It was also observed that the biochar exerted a greater influence in the PB composites. The results of a thermal conductivity test revealed that biochar matrices exhibit lower thermal conductivity than concrete. Also, the production of PB composite matrix tiles appears to be more cost-effective than CCTs, and has the potential to reduce the building industry's overall carbon footprint.

There are specific aspects of this study that merit further investigation, notably the long-term performance and durability of PB composites. Additionally, exploring and scrutinizing the potential for contaminant leaching from these PB composites would be a worthwhile pursuit.

Data Availability Statement

All data generated or used during the study appear in the published article.

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