Open Access Research Journal of
Science and Technology
Journals home page: https://oarjst.com/
ISSN: 2782-9960 (Online)

OARJ OPEN ACCESS RESEARCH JOURNALS

(Review Article)

Check for updates

Innovative approaches to upcycling plastic waste into sustainable construction materials: Addressing the global plastic pollution crisis

Victor O Hammed [1], Anuoluwapo Blessing Bello [2, *], Oluwakayode Olawale Olatunji [3] and Oladipo Owoyomi [4]

[1] *Engineering Consulting, Planet 3R, Ibadan, Nigeria.*
[2] *Project Management, Saint Louis University, Missouri, USA.*
[3] *Construction Project Management, Robert Gordo University, Aberdeen, Scotland UK.*
[4] *Nursing, Ball State University, Muncie, IN, USA.*

Open Access Research Journal of Science and Technology, 2024, 12(02), 094–102

Publication history: Received on 13 September 2024; revised on 04 November 2024; accepted on 04 December 2024

Article DOI: https://doi.org/10.53022/oarjst.2024.12.2.0143

Abstract

There are several environmental issues pressingly diminishing our planet in the 21st century, one of them is inarguably the environmental degradation through plastic waste. It is, however, imperative to explore creative solutions in order to lessen or eradicate the harm caused by the millions of tons of plastic waste that enter the environment annually, reusing plastic waste to make sustainable building materials is one promising strategy. This review looks at recent advancements in the upcycling of plastic waste, with an emphasis on ways to incorporate plastic into building materials like asphalt, bricks, and concrete. In order to scale these solutions, the paper examines potential future research and policy directions while evaluating the technical, financial, and environmental issues related to these technologies.

Keywords: Plastic Pollution; Environmental Sustainability; Sustainable Construction; Plastic Waste Upcycling; Plastic Recycling

1. Introduction

1.1. The Plastic Pollution Crisis

The production of plastic has grown exponentially over the decades, with over 300 million tons manufactured annually. A significant proportion of this vast quantity is discarded as waste, contributing to what has now become a dire global environmental crisis [1, 2]. Plastics possess remarkable characteristics such as resilience to natural deterioration and exceptional durability, which have made them indispensable in various industries and applications. However, these same attributes have resulted in the unchecked accumulation of plastic waste in landfills and natural habitats, including rivers, forests, and oceans. This buildup poses severe ecological threats and disrupts natural ecosystems.

Alarming projections suggest that the mass of plastic in the ocean may exceed the combined weight of all marine fish species in the near future. In fact, by 2020, the balance between plastic and aquatic life in the ocean had already tilted significantly in favor of waste materials. This grim reality has amplified calls for immediate and effective interventions to combat the mounting plastic pollution crisis. Policymakers, environmental organizations, and scientific communities worldwide are urging the adoption of sustainable practices, innovative technologies, and public awareness campaigns to mitigate the catastrophic impacts of plastic waste on our planet [3, 4].

* Corresponding author: Anuoluwapo Blessing Bello

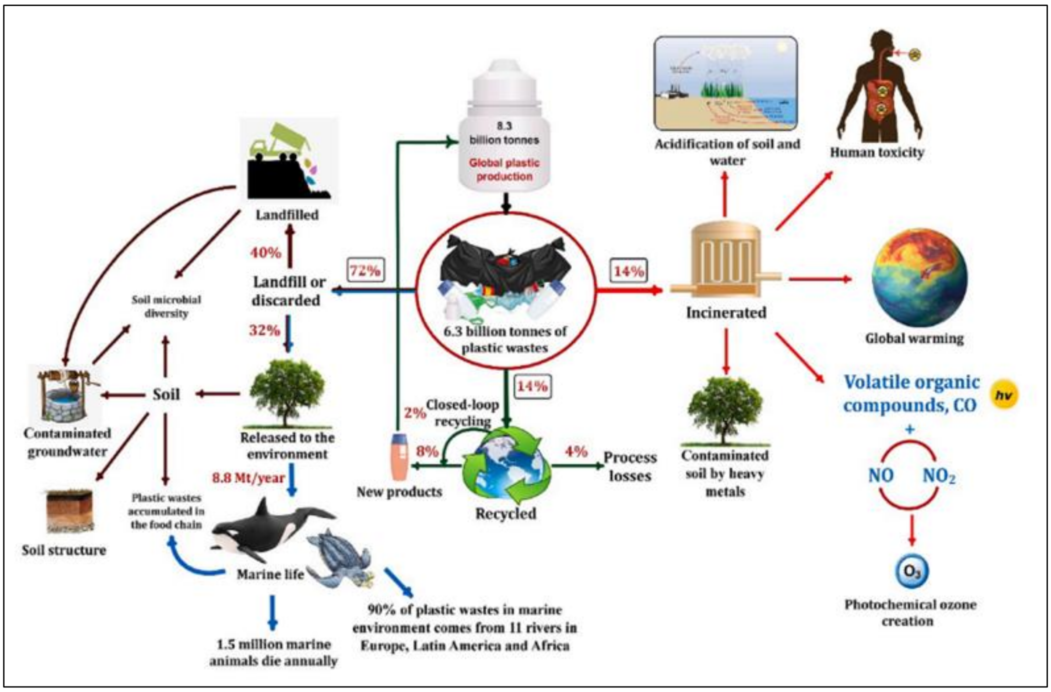

Figure 1 Illustration of the fate of plastic materials with harmful impacts on the eco-system. [4]

1.2. Plastic in Construction Materials: An Emerging Solution

Upcycling plastic waste into environmentally friendly building materials is innovative and creative way to reduce plastic pollution. Incorporating plastic waste into products like concrete, bricks, and asphalt can help the construction industry, which is a big consumer of raw materials and a major source of CO_2 emissions. In addition to reducing plastic waste, this strategy meets the construction industry's need for more environmentally friendly building materials [5, 6]. This review's goals are to examine the state of the art in the field of plastic waste upcycling in construction, highlight significant technological developments, and describe the obstacles and prospects for further research.

2. The Global Plastic Waste Problem

2.1. Plastic Production and Waste Generation

Plastic production has skyrocketed since the 1950s, with cumulative production now exceeding 8.3 billion metric tons [7]. Of this, only 9% has been recycled, while the majority is either incinerated or landfilled [8]. The low recycling rate is due to the complexity of sorting and processing different types of plastics, along with the economic inefficiencies associated with current recycling technologies [9, 10].

2.2. Environmental and Health Impacts of Plastic Pollution

Plastic waste has disastrous effects on the environment, especially in marine ecosystems where it decomposes into microplastics that marine life consumes and disrupts the food chain. Additionally, when burned, plastic waste pollutes the air and degrades the land. With plastic wastes being ubiquitous, high-level of threat is posed on the environment and the health of every living thing. Significant health risks are associated with the persistence of plastic waste on land, including the potential for hazardous chemicals to seep into soil and groundwater [11–14].

2.3. The Need for Circular Solutions

The linear economy model, in which plastics are produced, used, and discarded, has proven unsustainable. A shift toward a circular economy, where waste is minimized, and materials are continuously reused, is critical to addressing the plastic pollution crisis. Upcycling plastic waste into construction materials represents one promising solution within this circular economy framework, offering both environmental and economic benefits [15].

3. Upcycling Plastic Waste into Construction Materials

3.1. Overview of Plastic Upcycling in Construction

The process of turning waste materials into new products with greater value or functionality is known as upcycling. Waste plastic can be incorporated to a variety of building materials, including bricks, concrete, and asphalt, serving as additives to improve their qualities or to replace more conventional materials [16–18]. The main advancements in upcycling technology are examined in this section.

3.2. Plastic-Modified Concrete

Concrete is one of the most commonly used building materials, and incorporating plastic waste into concrete production has sparked significant interest. Plastic-modified concrete is typically made by partially replacing conventional aggregates like sand and gravel with plastic waste. This method not only reduces the use of natural resources, but it also has the potential to improve performance characteristics [19, 20].

- **Plastic Aggregates**: Plastic waste, particularly from polyethylene (PE), polyethylene terephthalate (PET), and polypropylene (PP), has been used as a substitute for fine and coarse aggregates in concrete. Studies have shown that the incorporation of plastic aggregates can improve the flexibility and crack resistance of concrete. However, challenges remain in achieving the desired strength and durability, as plastic aggregates tend to weaken the mechanical properties of concrete [21-23].
- **Plastic Fibers in Concrete**: Another approach involves adding plastic fibers to concrete mixes. These fibers, derived from waste plastics, can enhance the tensile strength and ductility of concrete, making it more resistant to cracking and shrinkage. This method shows promise for applications such as pavement and road construction [24, 25].

3.3. Plastic Bricks and Blocks

Plastic waste has also been upcycled into bricks and building blocks. These plastic-based bricks can be produced by either molding plastic waste into bricks directly or mixing it with traditional brick materials [26].

- **Molded Plastic Bricks**: In some regions, such as Africa and Asia, molded plastic bricks have been developed using plastic waste, particularly from single-use plastics [27]. These bricks are lightweight, durable, and offer good insulation properties. The molding process involves melting plastic waste and shaping it into brick forms, which can then be used in construction projects [28, 29]. However, concerns over the thermal degradation of plastics and the emission of toxic fumes during production must be addressed to ensure the safety and sustainability of this approach [30].
- **Plastic-Infused Clay Bricks**: Traditional clay bricks can also be modified by adding plastic waste to the mix before firing [31, 32]. This method reduces the consumption of natural clay resources and lowers the energy required for firing, as plastic burns off during the process, leaving behind pores that enhance insulation [33].

3.4. Plastic in Asphalt Pavements

The use of plastic waste in asphalt pavements has gained popularity as a means of improving road durability and reducing plastic pollution.

- **Plastic-Modified Asphalt**: In plastic-modified asphalt, plastic waste is added to the bitumen binder or mixed with the aggregate before laying the asphalt. Studies have shown that incorporating plastic into asphalt can improve its resistance to deformation, cracking, and water damage, thus extending the lifespan of roads [34-36]. This method has been successfully implemented in countries such as India, where plastic roads have demonstrated superior performance under high traffic loads and extreme weather conditions [37].
- **Waste plastics in Asphalt**: Through variety of further processes, waste plastics can be utilized as asphalt modifiers. Waste plastics were processed into forms in the early dates (fig 2a) and the intention was to directly incorporate them in the asphalt manufacturing plant. 100% waste plastics were use to produce these pellets, with their sizes ranging between 0.3 mm to 0.5 mm. [38] For instance, waste cans and PET bottles were cut by Modarres et al. [39], and by making use of a special crusher, they crushed them into flake form, see figure 2c. Modified asphalt were made into fiber form (< 2mm) and thin strip form (20 x 3 mm^2) by Lin et al. [40] and Kumar et al. [41] Moreso, electronic-plastic (e-waste) powder and waste HDPE powder have been used in asphalt modifiers [42, 43] as shown in figure 2d.

Figure 2 Various forms of waste plastics used as modifiers: (a) Pellet [44]; (b) shredding [39]; (c) flake [44]; (d) powder [45]

3.5. Approaches used to incorporate Waste Plastics into Asphalt

Waste plastics can be incorporated into Asphalt through two major approaches; the wet process and the wet process. [47] The wet process involves mechanical mixing procedure at high temperature. Waste plastic is directly added into asphalt binder to achieve a homogenous plastic-modified blinder blend. The asphalt binder and the waste plastic source are the deciding factor for the mixing time and temperature. In the dry process, the asphalt mixture and waste plastics are directly added, either as a mixture modifier or as a partial aggregate replacement. In the wet process, when the addition of waste plastic is performed, the properties of these asphalt are being modified by the waste plastics before they come in contact with the aggregates [48]. The waste plastic used in dry processes are used as reinforcement materials in the aggregates [38].

Table 1 The advantages and drawbacks of different processes [49]

Method	Production Cost	Technological Problem		Performance of Mixture	
		Advantage	Drawback	Advantage	Drawback
Wet process	Expensive (AC-16)	Normative guidance and engineering experience	Complex production process (specialized mixing and storage facilities)	Higher viscosity	Poor storage stability
Dry process	Cheap (AC-16)	Lack of normative guidance	Simple production process (no need of professional facility)	-	Poor water stability

- **Challenges and Opportunities**: Despite the promising results, challenges remain in standardizing the mix design for plastic-modified asphalt, as different types of plastics and mixing methods can result in variations in performance [50, 51]. Further research is needed to optimize the process and ensure consistent quality across different projects.

4. Benefits and Challenges of Plastic Waste Upcycling

4.1. Environmental Benefits

The upcycling of plastic waste into construction materials offers numerous environmental benefits that contribute to a more sustainable and eco-friendly construction industry:

- **Reduction in Plastic Waste:** Upcycling plastic waste for construction diverts plastics from landfills and incineration, significantly reducing plastic pollution, which contributes to environmental degradation [52]. This also helps alleviate the pressure on waste management systems, especially in urban areas where landfill space is limited [53].
- **Conservation of Natural Resources:** The incorporation of plastic waste into construction materials helps lower the demand for traditional raw materials such as sand, gravel, and clay. This conservation effort reduces

the environmental impact of resource extraction, including habitat destruction, biodiversity loss, and soil erosion [54, 55].

- **Reduction in CO_2 Emissions:** By substituting traditional materials with plastic-based alternatives, CO_2 emissions are lowered due to the reduced energy demands in the production process [56]. For instance, plastic-modified concrete is lighter and easier to process than conventional concrete, leading to lower energy consumption during production [30]. This reduction aligns with global efforts to achieve net-zero emissions in the construction sector.
- **Extended Material Lifecycle:** Upcycling extends the lifecycle of plastic waste by giving it a new application in the construction sector, thereby slowing the accumulation of waste in the environment and promoting circularity within industries [47].

4.2. Economic Advantages

Upcycling plastic waste into construction materials provides economic benefits that can contribute to more cost-effective and inclusive infrastructure development:

- **Affordable Building Materials:** Due to its low cost and wide availability, plastic waste is an affordable alternative for building materials, especially in developing and low-income areas. To reduce construction costs and enable the implementation of resilient, low-cost housing solutions, upcycled plastic materials can be used in affordable housing and essential infrastructure projects.[58].
- **Job Creation:** The plastic upcycling process, which includes collection, sorting, processing, and manufacturing, has the potential to create a range of employment opportunities. This demand for labor supports local economies and contributes to poverty reduction, particularly in regions where waste management and recycling industries are emerging sectors [59, 60].
- **Support for Circular Economy**: In a circular economy where materials are reused instead of being discarded, the integration of plastic waste into new products contributes to a great deal. This can attract investment in recycling and waste-to-resource industries, boosting economic growth and supporting sustainable business models [61-62].

4.3. Technical and Environmental Challenges

While promising benefits are presented through upcycling plastic waste into construction materials, it also faces multiple environmental and technical challenges that need to be addressed in order to witness its global and widespread adoption:

- **Mechanical Properties:** One of the primary technical challenges is ensuring that plastic-based construction materials meet essential mechanical standards such as compressive strength, durability, and thermal resistance. Although plastic-modified materials may offer improved flexibility and crack resistance, their reduced compressive strength compared to traditional materials can limit their application in load-bearing structures [63].
- **Fire and Toxicity Concerns:** When used in construction, plastic materials present serious toxicity and fire safety hazards. Plastic materials can emit harmful fumes when exposed to high temperatures or when they burn, which could have an impact on the quality of the air both indoors and outdoors. This is especially problematic for uses such as pavements or plastic bricks in crowded places where fire risks need to be reduced. [64].
- **Lack of Standardization:** Its reliable application is hampered by the lack of established standards for the use of plastic waste in building materials. Variations in plastic types, recycling techniques, and additives can result in inconsistent material performance, which makes quality control and regulation more difficult [65]. To guarantee that plastic-based materials satisfy safety, durability, and environmental standards across a range of construction applications, standardization efforts are required. [66].
- **Potential Environmental Leaching:** Some plastic waste products contain additives or microplastics, which can leach into the environment over time. This risk is especially relevant when these materials are used outdoors, where they may be subjected to rain, sunlight, and temperature fluctuations [67]. Concerns about leaching must be addressed by improving materials engineering and carefully selecting plastic types suitable for construction applications. [68].
- **Economic Viability and Scalability:** Scaling up plastic upcycling for the construction industry requires substantial investment in research, technology, and infrastructure. High initial setup costs and the need for specialized processing equipment can be a barrier, particularly for developing economies [69]. Overcoming

these cost challenges is essential to making plastic upcycling an economically viable solution for large-scale construction projects.

5. Future Directions and Policy Implications

5.1. Research and Innovation

To overcome the challenges associated with plastic upcycling, further research is needed in the following areas:

- **Material Science**: Advances in material science can help improve the mechanical properties of plastic-modified construction materials. Research into new plastic composites, as well as additives that enhance the bonding between plastic and other materials, could lead to stronger and more durable products.
- **Sustainable Production Methods**: Developing sustainable production methods that minimize energy consumption and reduce the emission of toxic fumes is critical to ensuring the long-term viability of plastic-based construction materials.
- **Circular Economy Integration**: Integrating plastic upcycling into broader circular economy strategies will be essential for maximizing the environmental and economic benefits of these technologies. This includes developing systems for the efficient collection, sorting, and processing of plastic waste, as well as creating markets for upcycled construction materials.

5.2. Policy and Regulation

Government policies and regulations will play a crucial role in promoting the adoption of plastic upcycling technologies:

- **Incentives for Upcycling**: Governments can encourage the development and use of plastic-based construction materials by offering financial incentives, such as tax breaks or subsidies, for companies that invest in upcycling technologies.
- **Standardization and Certification**: Establishing standardized guidelines and certification processes for plastic-modified construction materials will be essential to ensuring their safety and performance. This includes developing testing protocols to assess the mechanical properties, fire resistance, and environmental impact of these materials.
- **Public Awareness and Education**: Raising public awareness about the benefits of plastic upcycling can help drive demand for sustainable construction materials and encourage broader participation in recycling programs

6. Conclusion

The upcycling of plastic waste into sustainable construction materials offers a promising solution to the global plastic pollution crisis. By integrating plastic waste into products such as concrete, bricks, and asphalt, the construction industry can help reduce plastic waste, conserve natural resources, and lower CO_2 emissions. However, significant challenges remain in achieving the desired mechanical properties, addressing fire and toxicity concerns, and establishing standardized regulations. Continued research, innovation, and policy support will be essential to scaling these technologies and realizing their full potential in creating a more sustainable and circular economy.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Khoo, K. S., Ho, L. Y., Lim, H. R., Leong, H. Y., & Chew, K. W. (2021). Plastic waste associated with the COVID-19 pandemic: Crisis or opportunity? *Journal of hazardous materials*, *417*, 126108.

[2] Singh, P., & Sharma, V. P. (2016). Integrated plastic waste management: environmental and improved health approaches. *Procedia Environmental Sciences*, *35*, 692-700.

[3] Luan, X., Kou, X., Zhang, L., Chen, L., Liu, W., & Cui, Z. (2022). Estimation and prediction of plastic losses to the environment in China from 1950 to 2050. *Resources, Conservation and Recycling*, *184*, 106386.

[4] Lusher, A., Hollman, P., & Mendoza-Hill, J. (2017). *Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety*. FAO.

[5] Roy, P. S., Garnier, G., Allais, F., & Saito, K. (2021). Strategic approach towards plastic waste valorization: challenges and promising chemical upcycling possibilities. *ChemSusChem*, *14*(19), 4007-4027.

[6] Zhao, X., Boruah, B., Chin, K. F., Đokić, M., Modak, J. M., & Soo, H. S. (2022). Upcycling to sustainably reuse plastics. *Advanced Materials*, *34*(25), 2100843.

[7] Schlanger, Z. (2018). Plastic Production Has Skyrocketed Since The 1950s.

[8] Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), e1700782.

[9] Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2115-2126.

[10] Vogt, B. D., Stokes, K. K., & Kumar, S. K. (2021). Why is recycling of postconsumer plastics so challenging? *ACS Applied Polymer Materials*, *3*(9), 4325-4346.

[11] Wang, Y. L., Lee, Y. H., Chiu, I. J., Lin, Y. F., & Chiu, H. W. (2020). Potent impact of plastic nanomaterials and micromaterials on the food chain and human health. *International journal of molecular sciences*, *21*(5), 1727.

[12] Ghaffar, I., Rashid, M., Akmal, M., & Hussain, A. (2022). Plastics in the environment as potential threat to life: an overview. *Environmental Science and Pollution Research*, *29*(38), 56928-56947.

[13] Akindele, E. O., & Alimba, C. G. (2021). Plastic pollution threat in Africa: Current status and implications for aquatic ecosystem health. *Environmental Science and Pollution Research*, *28*, 7636-7651.

[14] Jain, I., Reddy, A., & Rao, N. (2021). The Widespread Environmental and Health Effects of Microplastics Pollution Worldwide. *Fusion of Multidisciplinary Research, An International Journal*, *2*(2), 224-234.

[15] Bucknall, D. G. (2020). Plastics as a materials system in a circular economy. *Philosophical Transactions of the Royal Society A*, *378*(2176), 20190268.

[16] Zhao, X., Boruah, B., Chin, K. F., Đokić, M., Modak, J. M., & Soo, H. S. (2022). Upcycling to sustainably reuse plastics. *Advanced Materials*, *34*(25), 2100843.

[17] Oyenuga, A. A., Bhamidimarri, R., & Researcher, P. D. (2017). Upcycling ideas for sustainable construction and demolition waste management: Challenges, opportunities and boundaries. *International Journal of Innovative Research in Science, Engineering and Technology*, *6*(3), 4066-4079.

[18] Guselnikova, O., Semyonov, O., Sviridova, E., Gulyaev, R., Gorbunova, A., Kogolev, D., ... & Postnikov, P. (2023). "Functional upcycling" of polymer waste towards the design of new materials. *Chemical Society Reviews*.

[19] da Silva, T. R., de Azevedo, A. R. G., Cecchin, D., Marvila, M. T., Amran, M., Fediuk, R., ... & Szelag, M. (2021). Application of plastic wastes in construction materials: A review using the concept of life-cycle assessment in the context of recent research for future perspectives. *Materials*, *14*(13), 3549.

[20] Zulkernain, N. H., Gani, P., Chuan, N. C., & Uvarajan, T. (2021). Utilisation of plastic waste as aggregate in construction materials: A review. *Construction and Building Materials*, *296*, 123669.

[21] Lazorenko, G., Kasprzhitskii, A., & Fini, E. H. (2022). Polyethylene terephthalate (PET) waste plastic as natural aggregate replacement in geopolymer mortar production. *Journal of Cleaner Production*, *375*, 134083.

[22] Belmokaddem, M., Mahi, A., Senhadji, Y., & Pekmezci, B. Y. (2020). Mechanical and physical properties and morphology of concrete containing plastic waste as aggregate. *Construction and Building Materials*, *257*, 119559.

[23] Sojobi, A. O., Nwobodo, S. E., & Aladegboye, O. J. (2016). Recycling of polyethylene terephthalate (PET) plastic bottle wastes in bituminous asphaltic concrete. *Cogent engineering*, *3*(1), 1133480.

[24] Al-Hadithi, A. I., & Hilal, N. N. (2016). The possibility of enhancing some properties of self-compacting concrete by adding waste plastic fibers. *Journal of Building Engineering*, *8*, 20-28.

[25] Gu, L., & Ozbakkaloglu, T. (2016). Use of recycled plastics in concrete: A critical review. *Waste Management*, *51*, 19-42.

[26] Amjad, M. S., & Diaz-Elsayed, N. (2024). Evaluating the environmental impacts of brick production from waste plastic. *Manufacturing Letters*, *41*, 1683-1695.

[27] Uvarajan, T., Gani, P., Chuan, N. C., & Zulkernain, N. H. (2022). Reusing plastic waste in the production of bricks and paving blocks: A review. *European Journal of Environmental and Civil Engineering*, *26*(14), 6941-6974.

[28] Shiri, N. D., Kajava, P. V., Ranjan, H. V., Pais, N. L., & Naik, V. M. (2015). Processing of waste plastics into building materials using a plastic extruder and compression testing of plastic bricks. *Journal of Mechanical Engineering and Automation*, *5*(3B), 39-42.

[29] Lamba, P., Kaur, D. P., Raj, S., & Sorout, J. (2022). Recycling/reuse of plastic waste as construction material for sustainable development: a review. *Environmental Science and Pollution Research*, *29*(57), 86156-86179.

[30] Evode, N., Qamar, S. A., Bilal, M., Barceló, D., & Iqbal, H. M. (2021). Plastic waste and its management strategies for environmental sustainability. *Case Studies in Chemical and Environmental Engineering*, *4*, 100142.

[31] Kadir, A. A. (2012). An overview of wastes recycling in fired clay bricks. *International Journal of Integrated Engineering*, *4*(2).

[32] Phonphuak, N., Kanyakam, S., & Chindaprasirt, P. (2016). Utilization of waste glass to enhance physical–mechanical properties of fired clay brick. *Journal of Cleaner production*, *112*, 3057-3062.

[33] Kurmus, H., & Mohajerani, A. (2021). Energy savings, thermal conductivity, micro and macro structural analysis of fired clay bricks incorporating cigarette butts. *Construction and Building Materials*, *283*, 122755.

[34] Lim, S. M., He, M., Hao, G., Ng, T. C. A., & Ong, G. P. (2024). Recyclability potential of waste plastic-modified asphalt concrete with consideration to its environmental impact. *Construction and Building Materials*, *439*, 137299.

[35] Mashaan, N. S., Chegenizadeh, A., Nikraz, H., & Rezagholilou, A. (2021). Investigating the engineering properties of asphalt binder modified with waste plastic polymer. *Ain Shams Engineering Journal*, *12*(2), 1569-1574.

[36] You, L., Long, Z., You, Z., Ge, D., Yang, X., Xu, F., ... & Diab, A. (2022). Review of recycling waste plastics in asphalt paving materials. *Journal of Traffic and Transportation Engineering (English Edition)*, *9*(5), 742-764.

[37] Gopinath, K. P., Nagarajan, V. M., Krishnan, A., & Malolan, R. (2020). A critical review on the influence of energy, environmental and economic factors on various processes used to handle and recycle plastic wastes: Development of a comprehensive index. *Journal of Cleaner Production*, *274*, 123031.

[38] Li, M.; Zhang, M.; Rong, H.; Zhang, X.; He, L.; Han, P.; Tong, M. Transport and deposition of plastic particles in porous media during seawater intrusion and groundwater-seawater displacement processes. Sci. Total Environ. **2021**, 781, 146752.

[39] Modarres, A.; Hamedi, H. Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes. Mater. Des. **2014**, 61, 8–15.

[40] Lin, Y.; Hu, C.; Adhikari, S.; Wu, C.; Yu, M. Evaluation of Waste Express Bag as a Novel Bitumen Modifier. Appl. Sci. **2019**, 9, 1242.

[41] Kumar, P.; Garg, R. Rheology of waste plastic fibre-modified bitumen. Int. J. Pavement Eng. **2011**, 12, 449–459.

[42] Hinislioglu, S.; Agar, E. Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix. Mater. Lett. **2004**, 58, 267–271.

[43] Shahane, H.A.; Bhosale, S.S. E-Waste plastic powder modified bitumen: Rheological properties and performance study of bituminous concrete. Road Mater. Pavement Des. **2019**, 22, 682–702.

[44] Fang, C.; Liu, P.; Yu, R.; Liu, X. Preparation process to affect stability in waste polyethylene-modified bitumen. Constr. Build. Mater. **2014**, 54, 320–325.

[45] Balasubramanian, B.; Gopala Krishna, G.V.T.; Saraswathy, V.; Srinivasan, K. Experimental investigation on concrete partially replaced with waste glass powder and waste E-plastic. Constr. Build. Mater. **2021**, 278, 122400.

[46] Yue, H.; Bird, R.N.; Heidrich, O. A review of the use of recycled solid waste materials in asphalt pavements. Resour. Conserv. Recycl. **2008**, 52, 58–73.

[47] Li, M.; Zhang, M.; Rong, H.; Zhang, X.; He, L.; Han, P.; Tong, M. Transport and deposition of plastic particles in porous media during seawater intrusion and groundwater-seawater displacement processes. Sci. Total Environ. **2021**, 781, 146752.

[48] Movilla-Quesada, D.; Raposeiras, A.C.; Silva-Klein, L.T.; Lastra-González, P.; Castro-Fresno, D. Use of plastic scrap in asphalt mixtures added by dry method as a partial substitute for bitumen. Waste Manag. **2019**, 87, 751–760.

[49] F., Zhao, Y., & Li, K. (2021). Using waste plastics as asphalt modifier: A review. *Materials*, *15*(1), 110.

[50] Di Mino, G., Vijayan, V., Eskandarsefat, S., Venturini, L., & Mantalovas, K. (2023). Investigating the multi-recyclability of recycled plastic-modified asphalt mixtures. *Infrastructures*, *8*(5), 84.

[51] Nisar, J., Mir, M. S., & Vivek. (2024). Exploring the potential of waste plastic–modified asphalt: a systematic review of blending ratios, mixing conditions, and rheological properties. *Environmental Science and Pollution Research*, *31*(8), 11507-11528.

[52] Zhao, X., Korey, M., Li, K., Copenhaver, K., Tekinalp, H., Celik, S., ... & Ozcan, S. (2022). Plastic waste upcycling toward a circular economy. *Chemical Engineering Journal*, *428*, 131928.

[53] Hui, Y., Li'ao, W., Fenwei, S., & Gang, H. (2006). Urban solid waste management in Chongqing: Challenges and opportunities. *Waste management*, *26*(9), 1052-1062.

[54] Vishnu, T. B., & Singh, K. L. (2021). A study on the suitability of solid waste materials in pavement construction: A review. *International Journal of Pavement Research and Technology*, *14*(5), 625-637.

[55] Carranza, D. M., Varas-Belemmi, K., De Veer, D., Iglesias-Müller, C., Coral-Santacruz, D., Méndez, F. A., ... & Gaymer, C. F. (2020). Socio-environmental conflicts: An underestimated threat to biodiversity conservation in Chile. *Environmental Science & Policy*, *110*, 46-59.

[56] Mori, R. (2023). Replacing all petroleum-based chemical products with natural biomass-based chemical products: a tutorial review. *RSC Sustainability*, *1*(2), 179-212.

[57] Rose, C. (2019). *Systems for reuse, repurposing and upcycling of existing building components* (Doctoral dissertation, UCL (University College London).

[58] Soni, A., Das, P. K., Hashmi, A. W., Yusuf, M., Kamyab, H., & Chelliapan, S. (2022). Challenges and opportunities of utilizing municipal solid waste as alternative building materials for sustainable development goals: A review. *Sustainable Chemistry and Pharmacy*, *27*, 100706.

[59] Conlon, K., Jayasinghe, R., & Dasanayake, R. (2019). Circular economy: waste-to-wealth, jobs creation, and innovation in the global south. *World review of science, technology and sustainable development*, *15*(2), 145-159.

[60] Repp, L., Hekkert, M., & Kirchherr, J. (2021). Circular economy-induced global employment shifts in apparel value chains: Job reduction in apparel production activities, job growth in reuse and recycling activities. *Resources, conservation and recycling*, *171*, 105621.

[61] Hahladakis, J. N., Iacovidou, E., & Gerassimidou, S. (2024). Plastic waste in a circular economy. In *Environmental Materials and Waste* (pp. 99-134). Elsevier.

[62] Bucknall, D. G. (2020). Plastics as a materials system in a circular economy. *Philosophical Transactions of the Royal Society A*, *378*(2176), 20190268.

[63] Ribeiro, L. S., Stolz, C. M., Amario, M., Silva, A. L. N. D., & Haddad, A. N. (2023). Use of Post-Consumer Plastics in the Production of Wood-Plastic Composites for Building Components: A Systematic Review. *Energies*, *16*(18), 6549.

[64] Wichman, I. S. (2003). Material flammability, combustion, toxicity and fire hazard in transportation. *Progress in energy and combustion science*, *29*(3), 247-299.

[65] Shamsuyeva, M., & Endres, H. J. (2021). Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardization and market. *Composites Part C: open access*, *6*, 100168.

[66] Tecchio, P., McAlister, C., Mathieux, F., & Ardente, F. (2017). In search of standards to support circularity in product policies: A systematic approach. *Journal of cleaner production*, *168*, 1533-1546.

[67] Hahladakis, J. N., Velis, C. A., Weber, R., Iacovidou, E., & Purnell, P. (2018). An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. *Journal of hazardous materials*, *344*, 179-199.

[68] Do, A. T. N., Ha, Y., & Kwon, J. H. (2022). Leaching of microplastic-associated additives in aquatic environments: a critical review. *Environmental Pollution*, *305*, 119258.

[69] Erickson, E. D., Tominac, P. A., Ma, J., Aguirre-Villegas, H., & Zavala, V. M. (2024). Evaluating the economic and environmental benefits of deploying a national-scale, thermo-chemical plastic waste upcycling infrastructure in the United States. *Computers & Chemical Engineering*, *189*, 108800.