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Original Article

Analyzing the Feasibility of Manufacturing Paver Blocks using Recycled Waste Plastic: A Strategic Approach to Recycling Initiatives

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Abstract - *The escalating issue of plastic waste generation and disposal presents a pressing global concern, exacerbated by the exponential growth in plastic usage over the past two decades. This has led to significant environmental repercussions, necessitating effective recycling solutions to mitigate environmental impact and conserve natural resources. One promising avenue is the exploration of recycling waste plastic into paver blocks, offering potential benefits such as reducing the carbon footprint associated with cement usage in traditional paving block production. Various studies have examined different approaches to the composition, testing, and usability of these recycled plastic-based paver blocks. However, there remains ample scope for further research to optimize these methods, including exploring strategies to increase the proportion of waste plastic utilized and investigating particle size variations. Key approaches discussed include fiber addition, adjusting percentages of high and low-density polyethylene, and incorporating polyethylene terephthalate alongside traditional materials. These conclusions provide valuable knowledge on how to use waste plastic effectively in sustainable construction practices and efforts to protect the environment.*

Keywords - *Paver block, Waste plastic, Carbon footprint, Cement, HDPE, LDPE.*

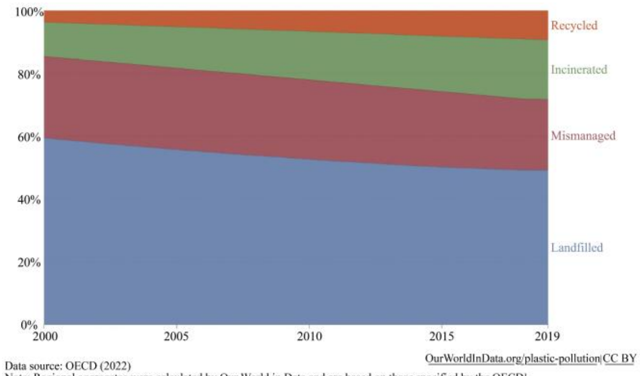
1. Introduction

Plastic waste has become a pressing environmental issue worldwide due to its widespread use, longevity, and improper disposal practices. Understanding its generation, sources, effects, and recycling methods is crucial for mitigating its impact on the ecosystem. Plastic waste originates from various sources like packaging, Consumer goods, Industrial processes, Urbanization and infrastructure, Food packaging, etc. Single-use plastic packaging, such as bottles, bags, and wrappers, contributes significantly to plastic waste generation due to its widespread use in industries and households. Items like disposable cutlery, straws, and packaging materials used in consumer goods add to the accumulation of plastic waste. Plastic waste is also generated during manufacturing processes in industries producing plastic products, leading to scraps, offcuts, and packaging materials.

Urbanization and construction activities contribute to plastic waste using plastic-based materials in infrastructure development, such as pipes, cables, and building materials. Generally, fast development comes with the exploitation of the environment. After 1970, the usage of plastics increased tremendously, which led to the spoiling of the environment.

Plastic waste contaminates land, water bodies, and marine ecosystems, posing threats to wildlife and marine life through destruction of habitat, entanglement and ingestion. Plastic waste degrades into microplastics over time, infiltrating soil, water, and food chains, with potential long-term effects on human health and ecosystems. The production of plastic materials requires significant energy and resources, contributing to resource depletion and environmental degradation. Inadequate waste management infrastructure and cleanup efforts result in economic losses due to environmental damage, health impacts, and reduced tourism revenue. Recycling waste plastic holds significance not only from economic and solid waste management perspectives but also from an environmental standpoint. As per the data provided by the OECD and processed by our world data, approximately 9% of waste plastic is recycled.

Recycling offers a sustainable solution to palliate the effect of plastic waste. Plastic waste is collected, sorted, and segregated based on type, color, and quality to facilitate the recycling process. The most common method is mechanical recycling, followed by shredding and melting to produce recycled pellets or flakes.



Data source: OECD (2022)
Note: Regional aggregates were calculated by Our World in Data and are based on those specified by the OECD[1].

Fig. 1 Waste plastic disposal method data [1]

These materials can be used to manufacture new plastic products. Chemical reactions in recycling processes break down polymers into their constituent molecules, allowing them to produce virgin-quality plastic or other chemicals. Innovative approaches such as upcycling repurpose plastic waste into higher-value products used at large scale. Efforts to promote waste reduction, improve recycling infrastructure, and raise awareness about responsible consumption and disposal practices are essential to address the plastic waste crisis and transition towards a circular economy. Raw material availability is not a concern. Researchers have used different binding materials, and some of them used plastic waste in proportion to cement. Few authors have defined the usage of HDPE and LDPE as constituting binders. Some authors have addressed the waste water bottle plastic, which contains mainly PET with cement. If we could make a product which is used on a large scale, from waste plastic only, then it would solve the major issue of today's world. It draws the attention that if only LDPE is used will lead to a strength issue, or only HDPE will solve the said problem. The possibility of usage of only HDPE for block manufacturing is a concern about its compressive strength. Compressive strength is a concern because of its application.

2. Literature Review

Due to the slow decomposition rate of waste plastic, researchers have been actively working towards finding convenient ways to utilize unwanted plastic. Numerous Marine lives die every year due to waste plastic, a well-known fact. Similar incidents are happening on the land, too. It has been observed that paver blocks manufactured with waste plastic have vast applications in regions with lower load-bearing [2]. Plastic, due to its versatility, durability, and affordability, has become a ubiquitous material in modern society.

Nevertheless, the use of plastic has led to a remarkable surge in plastic trash, mostly caused by fast urbanization and growth. Plastics, namely Polyethylene Terephthalate (PET), are currently seeing a significant increase in production because of their extensive utilization in everyday tasks such as the creation of bottles, containers, and supermarket bags [3]. The disposal of waste plastics has been a prominent environmental concern in recent times, mainly because they have a poor capacity to break down naturally and exist in large amounts for extended periods, often lasting for decades or even centuries. There are four major methods for handling plastic waste: landfilling, incineration, biodegradation, and recycling [3]. Between the 1950s and the 2000s, the use of plastic material increased enormously [4].

As reported by the UN Environment Programme [1], the yearly worldwide output of plastic garbage has reached an astonishing 400 million tons. Scientists have investigated several forms of waste plastic as possible substitutes for conventional aggregates in the production of concrete. The materials encompass EPS, HDPE, PET waste bottles, polypropylene fibers, and polyethylene bags. When considering alternatives to cement for manufacturing paver blocks, several properties, such as compressive strength, water absorption, and skid resistance, come into the picture. Reinforcement can significantly enhance material properties for specific applications. For instance, adding just 0.5% basalt fiber, 4mm in length, can raise compressive strength by 20.5% and fall down the water absorption by 50.5% [2]. The accumulation of plastic debris in ecosystems poses a grave threat to marine lives and environmental sustainability due to its sheer volume. Another viable option involves utilizing glass fiber to enhance properties. This typically entails substituting 0.1% to 0.3% of cement by weight with glass fiber and replacing 10% to 30% of regular aggregate with plastic aggregate [3]. Practical results of mixtures constitute plastic waste and particular sand suggest that a ratio of 1:4, with a sand composition of 80%, possesses the highest compressive strength for I-section blocks and brick paver blocks [4].

Additionally, studies have presented that the use of 0.5% basalt fiber raises compressive strength by approximately 20.5% and reduces water absorption by almost 50.5% [5]. Furthermore, incorporating glass fiber and plastic aggregate, with substitutions ranging from 0.1% to 0.3% of cement by weight and 10% to 30% of the regular aggregate, respectively, can enhance the compressive strength of paver blocks [6]. Moreover, the optimum ratio for compressive strength in paver blocks, achieved through mixtures containing plastic waste and particular sand, is noted to be 1:4 with sand composition of 80% [7].

Environmentalists share concerns about the environmental impact of increasing cement production, particularly regarding Carbon dioxide (CO_2) emissions [12]. Additionally, HDPE and HDPP are indeed two of the most extensively used plastic resins globally by volume, which raises environmental discernments [8]. The research seeks to identify strategies for mitigating the expansion of stone quarries or natural stone extraction. The classification of paving blocks is on the basis of their usage class, as stated in SNI 03-0691-1996. One of these classes is C quality, which is explicitly designed for pedestrian use [9]. The optimal plastic content is 20%, allowing for the casting of M20 grade concrete paver blocks suitable for heavy foot traffic areas or streets [10].

An evaluation of LDPE-sand paver blocks revealed a correlation between decreased sand particle size and increased strength in compression. Thus, utilizing finer sand particles of diameter less than 0.42 mm LDPE-sand block production offers significant advantages compared to using coarser sand [11-15]. The compressive strength of plastic paver blocks is recorded at 10.93 N/mm², slightly lower than the 11.96 N/mm² exhibited by cement paver blocks.

However, considering the potential of paver blocks made from recycled plastic waste as a viable alternative, comprehensive validation from all perspectives is essential [11]. It shows that improvement is still possible to compete with the strength available in cement blocks. Paver blocks crafted from a blend of plastic waste, other constructional materials, and waste constructional materials have demonstrated better performance [12]. However, it is suggested that paver blocks manufactured this way should be used in light-traffic areas. Attainment of final strength will be in a day in composite block compared to cement paver block is the advantage. Water absorption issues can also be solved by using waste plastic paver blocks [13]. In short paver block manufacturing from waste plastic is the way for sustainable construction. The compressive strength for different coarse aggregates is high from 2.5% to 4%, while decreases at 10% coarse aggregate [14].

The degradation rate of plastic is a concern for environmental impact. Soaking the plastic paver block in water for 60 days results in degradation, and it becomes microplastic [15]. Reducing cement consumption, if feasible for cement-based products like mortar, concrete, and paving blocks, could significantly decrease CO2 emissions. Various aggregate properties influence concrete performance, necessitating careful material selection. Concerns regarding plastic waste disposal methods, particularly in developing countries, are paramount. Common methods like landfill dumping, incineration, and open littering pose environmental and health risks.

Dumping plastic waste in landfills pollutes soil and water, with plastics taking hundreds to thousands of years to decompose, releasing harmful chemicals. Rainwater can carry these chemicals into groundwater, contaminating ecosystems and endangering human health. Incineration, while reducing waste volume, emits toxic gases and particulate matter, contributing to air pollution and respiratory issues. It also produces hazardous by-products like dioxins and furans. Open littering spoils environments threatens wildlife, and can lead to flooding and pollution. A glimpse of waste plastics and greenhouse gas generation in 2019 is depicted in Figure 2 to 5.

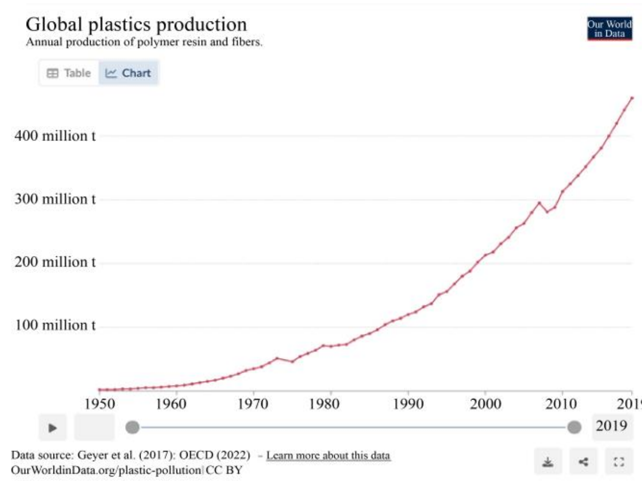


Fig. 2 Global waste plastic generation over the years [1]

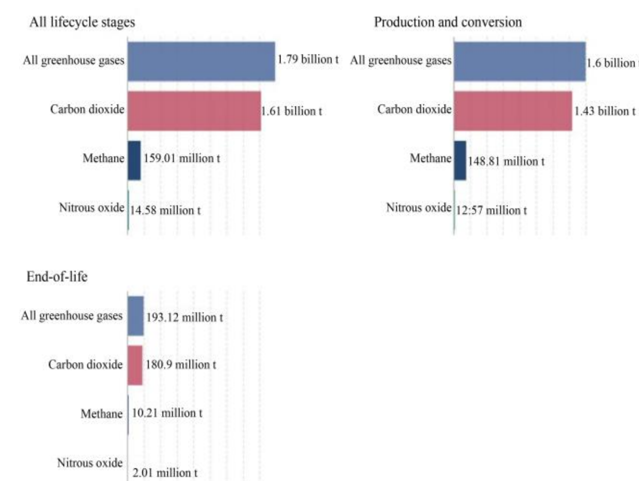


Fig. 3 Greenhouse gas generation from plastic waste [1]

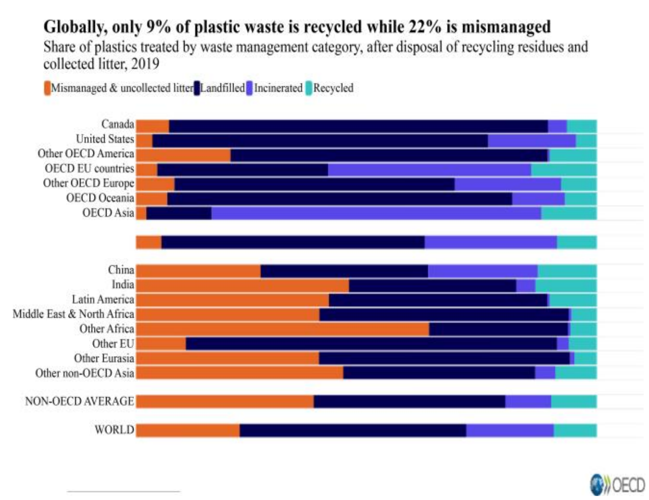


Fig. 4 Waste plastic recycled worldwide [1]

3. Material and Methods

The following general process steps were followed for the recycling of waste plastic to generate effective usage in paver block production:

3.1. Material Selection and Preparation

The first step is to select plastic trash that can be utilized for manufacturing paver blocks, considering elements including the chemical makeup, dimensions, and accessibility of waste materials. The next step is to ensure proper sorting and cleaning of collected waste to remove contaminants and enhance material quality for recycling. After that, different recycling methods are investigated for processing waste into suitable forms for paver block manufacturing, such as shredding, melting, and extrusion.

3.2. Manufacturing Process Optimization

Development of optimized manufacturing processes for incorporating recycled plastic waste into paver block production to ensure compatibility with existing equipment and techniques.

Experiment with different formulations and ratios of recycled plastic to other materials (e.g., aggregates, binders) to achieve the desired performance and durability of paver blocks.

Implement quality control measures to monitor material consistency, block dimensions, and surface finish during production.

3.3. Laboratory Testing

Perform wide-ranging laboratory tests on manufactured paver block samples to evaluate properties such as water absorption, crushing strength, compressive strength, resistance to heat, impact and chemical corrosion, heat absorption, etc.

Compare test results of recycled plastic-containing paver blocks with conventional blocks to assess performance and identify areas for improvement.
Implement rigorous quality assurance protocols to ensure compliance with relevant standards and specifications for paver block materials.

3.4. Environmental and Economic Assessment

Conduct life cycle assessments to evaluate the impact on the environment (e.g., carbon footprint, resource consumption) of using recycled plastic in paver block production compared to conventional materials.

Perform cost analyses to evaluate the economic feasibility and viability of integrating recycled plastic into paver block manufacturing processes, concerned with factors like material costs, production efficiency, and market condition.

3.5. Stakeholder Engagement and Outreach

Engage with stakeholders, including government agencies, industry partners, researchers, and community members, to raise awareness of the benefits of recycling plastic waste in paver block production.

Collaborate with local establishments and municipalities to establish policies and incentives that support the adoption of sustainable practices for plastic waste management and circular economy initiatives.

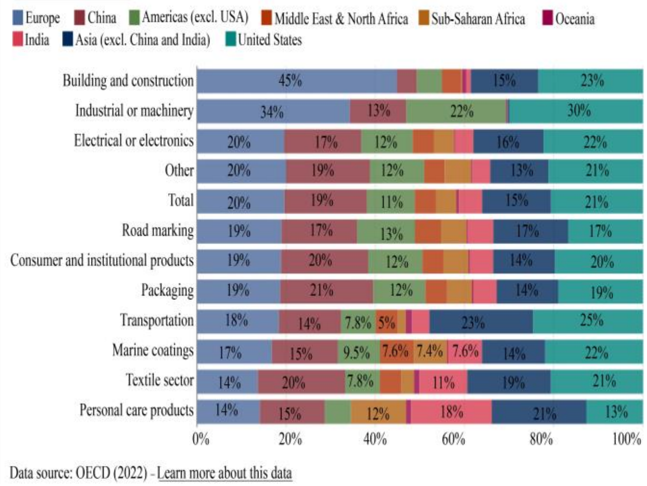


Fig. 5 Plastic waste generation, country and industrial sector wise [1]

3.6. Manufacturing Steps

Collection of Waste Plastics: Effective collection and segregation methods are crucial, with education and awareness programs being essential to encourage population participation.

Drying of Samples: Wet samples are dried adequately to remove water and facilitate further processing and analysis, also aiding in the elimination of bacteria and microorganisms.

- Manufacturing of Blocks: This involves batching, mixing, compaction, and curing processes.
- Batching of Waste Plastics: Precise measurement and selection ensure the correct proportions of plastic waste for uniformity in block properties.
- Mixing with Binders like Cement: Waste plastic is mixed with a binder, typically cement, to form a homogeneous mixture providing structural integrity to blocks.
- Heating plays a vital role in the molding process of raw materials. The temperature during this phase is a critical parameter as it directly influences the emission of products. It is a widely acknowledged fact that burning plastic is highly detrimental due to the release of toxic substances. Therefore, careful control of temperature becomes imperative.

Moreover, heating the material to its recrystallization temperature for compaction adds another layer of complexity to the analysis from an emission perspective. This process requires thorough scrutiny to ensure that emissions are minimized and do not pose any environmental or health hazards. Hence, a comprehensive understanding of the heating process and its impact on emissions is vital for sustainable manufacturing practices.

- Compaction is the final stage that entails curing the part to achieve specified dimensions, necessitating uniform compaction. This crucial step directly influences the properties of the final product. At this juncture, our primary concern is assessing the feasibility of utilizing waste plastic to manufacture beneficial products such as paver blocks. This involves meticulous examination to ensure that the compaction process is consistent and yields high-quality outcomes, contributing to both environmental sustainability and product efficacy.

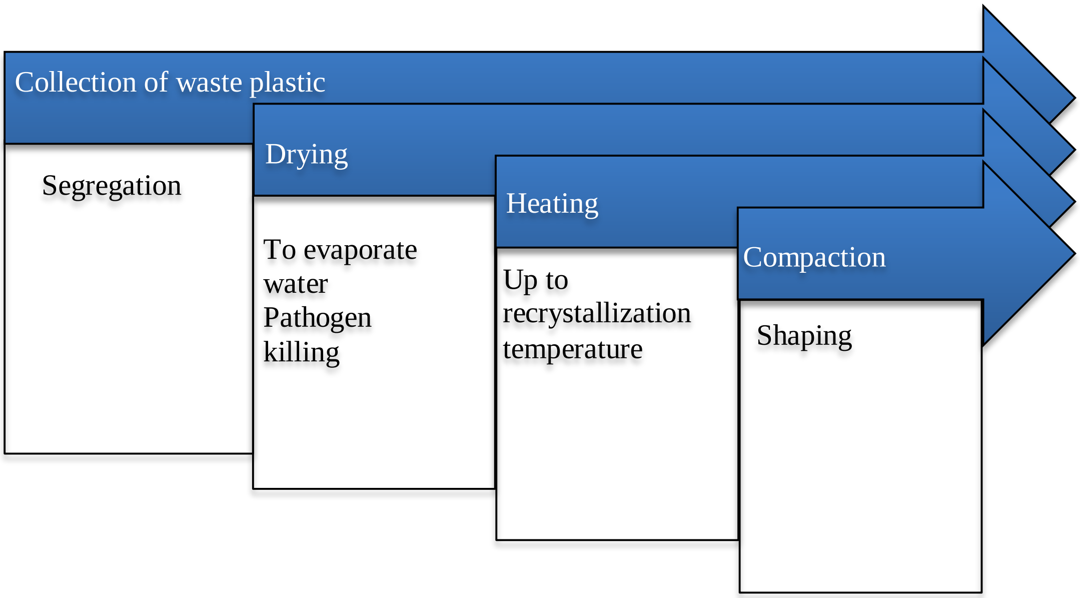


Fig. 6 Process flow diagram

4. Conclusion

In conclusion, the study highlights the viability of utilizing plastic material in paver block production, offering benefits such as reduced development time and improved resistance to chemical, physical, and mechanical reactions, particularly in regions with rapid manufacturing processes and high moisture levels. The incorporation of basalt fiber with waste plastic presents a promising avenue for decreasing cement usage while maintaining environmental sustainability. However, achieving widespread adoption of plastic-mixed paver blocks requires a multi-faceted approach. This includes improving waste management infrastructure, promoting recycling practices, implementing circular economy initiatives, raising awareness and education, and enacting supportive policy interventions. With only approximately 9% of plastic waste being recycled as of 2019, there is a growing demand for increased recycling efforts and innovative solutions in waste management. Overall, by embracing sustainable practices and harnessing the potential of recycled materials, the construction industry can contribute significantly to environmental conservation and resource efficiency.

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