ENHANCING THE PERFORMANCE AND SUSTAINABILITY OF PREVIOUS CONCRETE USING RECYCLED PLASTIC WASTE FOR FUTURE TRANSPORTATION INFRASTRUCTURE

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Abstract:

The rapid growth of urbanization and transportation demands has intensified the need for sustainable construction materials that balance durability, cost-efficiency, and environmental performance. Pervious concrete has gained attention in transportation infrastructure for its ability to facilitate storm water management, reduce surface runoff, and mitigate urban flooding. However, conventional pervious concrete faces challenges such as reduced strength, low durability, and clogging over time. To address these limitations, this study investigates the potential of integrating recycled plastic waste as a partial replacement for natural aggregates and binders in pervious concrete mixtures. By repurposing plastic waste—one of the most pressing environmental pollutants—into concrete, the dual objective of waste management and sustainable infrastructure can be achieved. The research evaluates mechanical properties (compressive strength, flexural strength, and permeability), durability (resistance to wear and clogging), and sustainability indicators (carbon footprint reduction and life-cycle performance). The findings highlight that recycled plastic incorporation can enhance the performance, extend the service life of pervious concrete, and contribute to eco-friendly solutions for future transportation networks.

I.INTRODUCTION

Concrete is the second most consumed material in the world after water, making its environmental impact a global concern. Conventional concrete production involves massive extraction of natural aggregates and emits significant CO_2 during cement manufacturing. This leads to depletion of natural resources, increased energy consumption, and contribution to climate change. To address these challenges, sustainable concrete technologies have been gaining momentum.

Pervious concrete is one such material designed to address environmental concerns related to storm water management, heat island effects, and groundwater depletion. Due to its porous structure, pervious concrete allows rainwater to infiltrate into the ground, reducing surface runoff and flooding risks. It is particularly useful in sidewalks, low-traffic roads, parking lots, and pavements. Despite its advantages, pervious concrete faces limitations in terms of strength, abrasion resistance, and long-term durability under vehicular loads.

In parallel, the world is facing an unprecedented plastic waste crisis. Plastics are lightweight, durable, and non-biodegradable, leading to accumulation in landfills and oceans. India alone generates more than 3.5 million tons of plastic waste annually, of which only a small fraction is recycled. Incorporating plastic waste into concrete not only reduces environmental hazards but also substitutes natural resources, creating a circular economy in construction.

This research focuses on combining the environmental benefits of pervious concrete with the waste management potential of recycled plastics. By using plastic as aggregate replacement, filler, or reinforcement, the study aims to enhance the mechanical, hydraulic, and sustainability aspects of pervious concrete, thereby supporting future sustainable transportation infrastructure.

II.RELATED WORKS

The use of recycled plastic waste in concrete has been investigated across different research domains—mechanical enhancement, permeability, durability, and sustainability. A few key studies include:

1. Incorporation of Plastic Aggregates

Choi et al. (2005): Substituted fine aggregates with PET bottle particles in concrete. Results showed reduction in density and compressive strength but improved ductility and toughness.

Bhogayata & Arora (2018): Demonstrated that shredded plastic in pervious concrete improved abrasion resistance and resistance to clogging, making it suitable for pavements.

2. Plastic as Fiber Reinforcement

Siddique et al. (2018): Investigated plastic fibers (polypropylene, PET) and found improved crack resistance, tensile strength, and post-cracking behavior.

Saikia & de Brito (2012): PET fibers enhanced flexural properties but required careful optimization of fiber length and aspect ratio.

3. Plastic in Sustainable Pavement Materials

Prakash et al. (2021): Explored 5–15% plastic aggregate replacement in pervious concrete pavements. Optimum levels enhanced compressive strength and reduced permeability loss due to clogging.

Yang & Jiang (2013): Reported that using recycled polymers in pervious concrete reduces cost and improves sustainability while maintaining permeability.

4. Life-Cycle & Sustainability Studies

Meyer (2009): Reviewed sustainable concrete innovations and emphasized plastics as a potential eco-friendly substitute in future infrastructure.

Pacheco-Torgal (2014): Stressed that construction must move towards recycling-based circular economy, where plastic waste plays a crucial role.

Summary of Related Works

From past studies, it is clear that:

- Plastic waste enhances ductility, toughness, abrasion resistance, and durability of concrete.
- Excess plastic (>20%) decreases compressive strength significantly.
- Pervious concrete with controlled plastic addition achieves a balance between permeability and strength.
- Integration of plastics aligns with circular economy principles for sustainable infrastructure.

III. MATERIAL PREPARATION

The preparation of materials plays a crucial role in achieving high-performance and sustainable pervious concrete. The following materials and their treatment methods are considered in this research:

1.Cement (Binder):

Ordinary Portland Cement (OPC 43/53 grade) is used as the primary binder. To enhance sustainability, supplementary cementitious materials (SCMs) such as fly ash or ground granulated blast furnace slag (GGBS) may be incorporated to partially replace cement, reducing the carbon footprint.

2.Coarse Aggregates:

Natural aggregates with sizes ranging from 4.75 mm to 12 mm are used. Their clean, uniform gradation ensures adequate porosity and strength in pervious concrete.

3. Recycled Plastic Waste:

Types: PET, HDPE, and LDPE plastics collected from municipal and industrial waste.

Processing: Waste plastic is cleaned, shredded, and processed into flakes or pellets. For certain mixtures, plastic is melted and reformed into coarse aggregate shapes.

Proportions: Partial replacement of 5–20% of coarse aggregate by volume is tested to optimize performance.

4. Fine Aggregates :

Since pervious concrete usually avoids fines to maintain permeability, limited quantities of fine plastic powder or sand may be used to balance strength and void content.

5. Water:

Potable water is used for mixing. The water-to-cement ratio is carefully maintained between 0.27–0.35 to achieve sufficient paste coating without blocking pores.

6. Admixtures:

Superplasticizers are used to improve workability without increasing water content. Fibers (optional, e.g., plastic or glass fibers) may be added to enhance ductility and crack resistance.

Mixing and Casting Process

Aggregates and shredded plastic waste are uniformly mixed in a dry condition.

Cement and SCMs are added, followed by water and admixtures.

The mixture is thoroughly blended to achieve a uniform distribution of plastic waste.

Specimens (cubes, cylinders, slabs) are cast and compacted with minimal vibration to maintain void structure.

Curing is done in moist conditions for 7, 14, and 28 days.

Performance Tests Conducted

Mechanical Properties:

Compressive strength

Flexural strength

Split tensile strength

1. Durability Tests:

- Permeability and porosity
- Abrasion resistance
- Freeze-thaw resistance
- Resistance to clogging

2. Sustainability Evaluation:

- Life Cycle Assessment (LCA) for carbon footprint reduction
- Resource efficiency through plastic waste utilization
- Cost-benefit analysis compared with conventional mixes

IV. RECYCLED PLASTIC WASTE AS AGGREGATE SUBSTITUTIVE

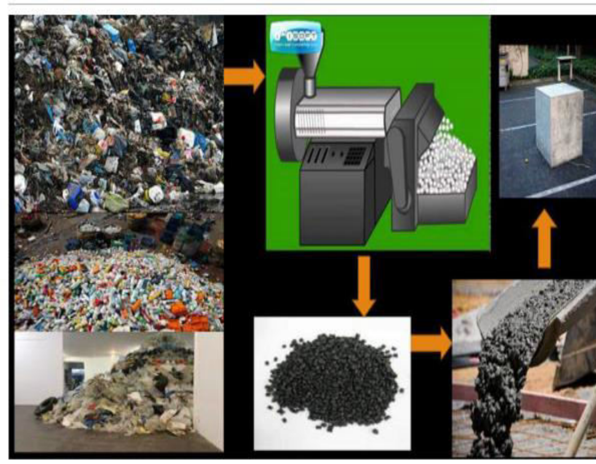

Fig 4.1 Plastic aggregate manufacturing process

Plastic is also utilized as a coarse or fine aggregate in many cases, which is very advantageous from an environmental perspective (Fig. 3). A study (Pacheco-Torgal, 2019) reported the effect of polyethylene terephthalate (PET) from plastic bottles as a partial substitute for sand (up to 50%) in concrete. As a common conclusion, recycled PET can be utilized in eco-friendly concrete production at certain replacement rates. This approach diminishes the self-weight of concrete in structures and can be used for non-structural elements that do not require high compressive strength due to the properties of such plastic, which are primarily different from other aggregates. Notice that the study states that the properties the aggregate substitutes primarily depend on the initial treatment given to plastic waste (Omary et al., 2016). Hence, sustainability in the concrete industry may be enhanced by using such plastic waste along with concrete to meet the requirements of sustainable building and improving thermal properties, reducing the use of natural resources, ingestion of waste, avoiding pollution, and saving energy (Ferriz-Papi and Thomas, 2017).

Several methods are adopted to use plastic in concrete at sites. The adoption of these methods also affects its effectiveness (Suchorab et al., 2020). The simplest way to utilize plastic as aggregate in the mixture is to mix the concrete simply adding plastic inside. This simple method allows producing batches in plants that can be used for multiple purposes (Aluko and Nna, 2014). The second method is to first heat the plastic and mix it with a coarse aggregate, then allow it to cool. After some time, plastic would strongly adhere to the aggregate (Zhang and Poon, 2018). Plastic, alongside aggregate, has several functions; it can fill some pores in the concrete as well as improve the concrete response in acoustic and thermal conductivity (Mokhatar et al., 2020). Notice that the bonding strength of plastic aggregates and the cement paste could be significantly influenced by the treatment of use for concrete production affecting its properties. So, if large amounts of plastic are used in the production of concrete, engineering properties and relationship of the added plastic material within concrete must be known (Barabah et al., 2019).

Studies reported that these aggregates from plastics represent a worthy advance in sustainable construction, maximizing thermal and acoustic insulation compared to mineral aggregates, and showing better construction quality and higher energy conservation (Zhang et al., 2015). Plastic aggregates are excellent to produce low CO2 concrete that is also intended to reduce the required structural supports and significantly lower transportation costs. Most literature review studies have focused on the effect of adding plastic wastes on the mechanical properties of concrete, with less focus on the physical properties such as acoustic and thermal insulation properties of concrete. In the following sub-sections these two properties are regarded.

V. ECONOMIC CONSIDERATION

Waste plastics have been used in different ways as fibers and aggregate (including fillers) for preparing concrete mixing. However, the application of plastic aggregates is more economical and simpler, as it generally involves fewer processing steps compared with that of fibers (Adela et al., 2020).The rising concern of the environmental damage caused by the utilization of natural aggregate has led to an interest in more conservative and cost-effective concrete materials (Attanasio et al., 2015). A study found that replacing 10% sand by volume with recycled plastic is a viable proposition that has the potential to save 820 million tons of sand every year (Needhidasan and Sai, 2020). Moreover, when accounting for installation costs, the price margin is dramatically reduced compared to conventional concrete, as plastic can be installed faster and using less labor due to its lightweight nature (Kaur and Pavía, An study carried out by Hussein and Abd Al-Ameer found that a polyethylene waste is 25 to 35% as a partial replacement of mortar is suitable. It has many benefits, including simplicity, cost, and energy savings, and clean recycling, because it is not harming the environment. In economic terms, 37% of the gravel cost can be decreased if the plastic bottles are utilized as coarse aggregate in concrete mixing (Siddique et al., 2008). On the other hand, Dhawan et al. (2019) reported that the potential benefits of using plastic waste as aggregate in concrete mixing are providing new, cost-effective building materials and ensuring the environmental sustainability of the new products.

The potential use of waste plastic improves the efficiency of construction materials. In that sense, the utilization of plastic in building concrete decreases the dead load, which will help in reducing the costs associated (Senhadji et al., 2019). Hama and Hilal (2017) presented that the utilization of crushed E-waste plastic material as conventional and other materials in the building construction helps in reducing the cost of concrete manufacturing. Besides, a Colombian company has developed a plastic brick made from recyclable plastic. As a case study they built a classroom in a remote ares in the country. The classrooms using plastic bricks cost approximately $14,500, each compared to conventional concrete construction at $16,500 (Pacheco et al., 2012). Finally, another example is given by Kaur and Pavia (2019), that mention that using recycled plastic (34%) by replacing sand with plastic waste in mortars and concretes leads to lower raw material extraction, with the consequent economy in fuel and carbon emissions.

VI.CONCLUSION

Plastic wastes have a global impact on the environment due to pollution. The spread of this waste in streets, parks, and rivers distorts the as major cause of increasing water and soil pollution which has negative impact to fauna, biodiversity and human health and well as the esthetic view of the cities. This urges researchers to exploit plastic waste to reduce its spread. Specifically, researchers in civil engineering can focus on using plastic waste in concrete manufacturing.

It has been demonstrated that the utilization of plastic within concrete upgrades the sound and thermal insulation. Considering the over exploitation of quarries to generate new conventional aggregates for concrete, plastic waste usage can reduce the superfluous natural resources used in building construction. It can also help us save a lot of energy and improve performance over the lifespan of the buildings. However, since plastic wastes have a lower density than the natural aggregates (fine and coarse), the overall weight of concrete is diminishing, creating lighter concrete and lower structural performance. Hence, the priority of the construction industry is sustainability and the analysis on how to design new non-structural building components with an efficient use of plastic waste.

To sum up, the use of plastic in concrete is an optimal solution for achieving environmental sustainability. Moreover, plastic wastes are ideal, economical, and safe materials to be utilized within the manufacturing of lightweight green concrete in buildings development, particularly for sound insulation, thermal insulation, and for achieving environmental sustainability.

VII.REFERENCES

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