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A WASTE MANAGEMENT SOLUTION IN CONSTRUCTION SECTOR: REPLACING THE NATURAL AGGREGATES IN CONCRETE WITH VARIOUS PLASTIC WASTES

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Abstract: Research into new and innovative uses of waste materials are continuously advancing. The use of recycled aggregates saves natural resources and dumping spaces, and helps to maintain a clean environment. This current study concentrates on those waste materials, specifically plastics to be used as substitutes for conventional materials, mainly aggregates, in ordinary Portland cement concrete mixes. Recycling plastics as aggregate offers a solution to the problems encountered with the quarrying of natural aggregates and the disposal of wastes. Integrating plastic waste into concrete transforms a major pollution problem into a resource, reduces reliance on finite natural materials, lowers environmental impacts, and advances sustainable waste management and construction. Plastic waste can be used as a partial replacement for natural coarse aggregates (gravel) in concrete, offering environmental benefits and potential improvements in some properties. This approach supports sustainable construction by recycling plastic waste and reducing reliance on natural gravel without severely compromising concrete quality.
Keywords: waste management, natural aggregates in concrete, plastic wastes

1. INTRODUCTION

CONCRETE is widely used construction material in the present industry, being among the world's greatest–produced building materials. Of natural resources extracted throughout history, approximately 80% has been within this last century. A growing population is definitely connected to the proper construction and sustainable infra–structure. It is expected that by 2050, more than 70% of the world's countries and territories will be more than 60% urban, and the remaining 30% will be at least 80% urban.

Figure 1. Concrete and its use in construction sector

Global concrete production is a massive and critical component of modern civilization, reflecting both human ingenuity and its environmental footprint. Here's a breakdown of key aspects, regarding the scale & growth:

- massive quantities: Concrete is the most consumed man–made material on Earth by volume. Global production is estimated at around 10–12 billion metric tons per year (as of recent years, like 2022–2023). Over 10 billion tons of structural concrete is used annually on construction sites around the world, with between 60% and 80% of this essentially made up of aggregate. Billion tons of fine and coarse aggregate are manufactured worldwide annually, solely to be used as concrete for constructed structures.
- steady growth: Production has roughly doubled every 20 years over the past half–century, driven by urbanization, infrastructure development, and economic growth, particularly in developing nations.

The global concrete production rate is estimated to be about one ton per person per year, and that this rate is continuously rising. With approximately 80% of conventional concrete comprising sand and stone, activities in their extraction and relocation harm the natural environment. Aggregate is traditionally produced by crushing sand and rock, the processes of which have significant impacts on the natural environment. Therefore, manufacturing concrete causes substantial amounts of ecological damage and energy consumption.

Figure 2. Aggregates

The concrete industry places a heavy demand on primary aggregate sources. There is therefore considerable incentive to develop alternative aggregate sources based on waste materials. The replacement of natural aggregate with various waste, therefore, theoretically removes this environmental damage and energy consumption. Waste as aggregate represents a potential solution to curtail the adverse impact of concrete on the natural environment.

2. ECOLOGICAL CONTEXT

Following a normal growth in population, the amount and type of waste materials have increased accordingly. Many of the non–decomposing waste materials will remain in the environment for hundreds, perhaps thousands of years. The non–decomposing waste materials cause a waste disposal crisis, thereby contributing to the environmental problems. The problem of waste accumulation exists worldwide, specifically in the densely populated areas. Most of these materials are left as stockpiles, landfill material or illegally dumped in selected areas. Large quantities of this waste cannot be eliminated. However, the environmental impact can be reduced by making more sustainable use of this waste.

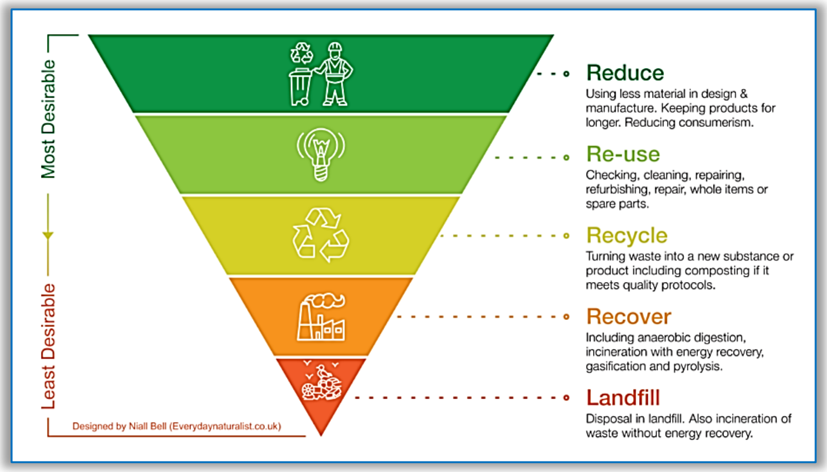

Figure 3. Waste Hierarchy

This is known as "Waste Hierarchy". Its aim is to reduce, reuse, or recycle waste, the latter being the preferred option of waste disposal. The waste hierarchy is concerned with establishing the best waste management options with respect to their environmental impact, with options that are best for the environment at the top of the hierarchy. In all circumstances, preventing waste in the first place is the preferred option, with landfill and incineration typically being the least desirable options. Moving the management option, where there is a choice, up the hierarchy should in theory reduce the impact of the resource on the environment.

RECYCLING, REUSING, and REPRODUCING waste materials that would otherwise burden the terrain and enclose small pockets of available land ultimately reduce the loss of land and the landscape. The concrete industry can be one of the major beneficiary of various wastes that can be a major source of reproducing building materials for new construction.

Nowadays, recycling is a common practice because it protects the planet's resources. Recycling and reapplication of waste tyres, and demolished residues like recycled concrete or brick debris are very much on the process and they can be successfully integrated into fresh concrete. Similarly, recycling waste glasses and plastics as an ingredient of concrete can serve as an alternative to natural aggregates and reduce potential risks to the environment.

The generation of waste plastic is a major concern for many countries as billions of products are ending their service life every year. The amount of plastic waste has gradually increased over the recent years due to urbanization and industrialization where most of these waste end up in landfill while only small fraction can be recycled because of the high cost of cleaning and sorting. Since plastics are not biodegradable, landfill is not an environmentally friendly solution. Recent studies have shown that the plastic waste can be effectively used in concrete either as aggregate (fine or coarse aggregate) or filler for microarming.

3. METHODS & POSSIBILITIES

Concrete comprises three major constituents (aggregate, cement, and water), the solid components being the cement, fine and coarse aggregates. Looking into its composition, it contains cement, sand, gravel, and water, and sometimes admixtures are added to achieve desired effects. Cement, being a binding material and a crucial element of concrete, makes up 8–15% portion of it. Aggregate makes up 60%–75% of the total volume of concrete, with the rest comprising water, cement, and additives. The proportion and type of ingredients change the concrete's properties.

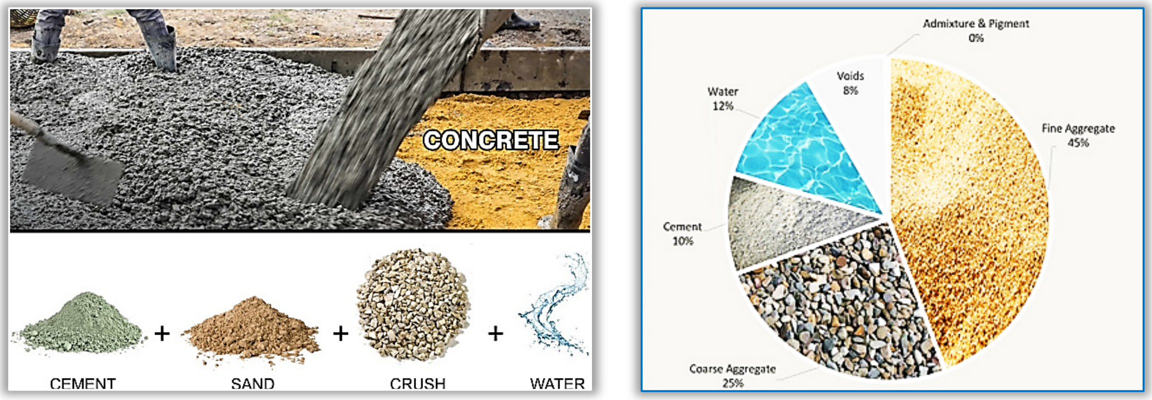

Figure 4. Concrete constituents

Concrete is a composite material made primarily of:

- Cement (8–15%): Usually Portland cement, made by heating limestone and clay in a kiln. This is the most energy–intensive and carbon–intensive component.
- Aggregates (60–75%): Crushed stone, sand, and gravel. Sand (especially fine aggregate) is a critical resource, leading to significant environmental concerns like riverbed depletion and coastal erosion.
- Water (14–21%): Triggers the chemical reaction (hydration) that binds the mixture.

Using recycled concrete aggregate, crushed glass or plastics, or industrial byproducts to reduce demand for virgin sand and gravel are serious alternatives to substitute natural aggregates. Various manufacturing waste substances as waste aggregates from the destruction of buildings, slag, fly ash, etc., have been attempted as extra material in concrete. Also, crushed recycled plastics can be used as a complete fine aggregate replacement in concrete. Repurposing plastic waste for use in concrete mixtures has simply involved crushing the plastics to a smaller size, as the first step in the process of recycling and reuse.

Global concrete production is colossal, essential for building our modern world. While alternatives and innovations are emerging, the sheer scale of production means that even incremental improvements

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have significant potential impact. The future challenge lies in efficient use of resources, while continuing to meet the growing global demand for this fundamental material.
The idea to substitute natural aggregate with various wastes has been driven by the steady reduction in natural resources, as well as the recent sustainability initiatives. Concrete salvaged from construction and demolition, as well as tires or waste plastics, can also be recycled into aggregate. For many decades' efforts had been devoted to using wastes in concrete.
The opportunity provided by the use of plastic waste in concrete is a potential solution that uses circular economy principles to unlock value and create new business opportunities: first, by finding a use for plastic products of higher value than landfill, and second by decreasing the negative externalities of the construction sector. By using plastic waste in concrete, it would be possible to:
- re–utilize the post–consumer plastic that is landfilled each year
- reduce the demand for virgin aggregates in concrete
- localize supply chains and contribute to the transition towards a circular economy

Diverting plastic products from landfill to be used to make concrete is a great example of cascading a technical material to another valuable use – one of the key principles of value creation in the circular economy.
The use of recycled waste as a replacement natural aggregate, its optimum mixing proportions, and their immediate and long–term effect on the strength and durability properties of concrete are still under investigation. However, it is expected to be a very good candidate for the replacement of natural aggregates.

4. COMMONLY STUDIED AND APPLIED RECYCLED PLASTICS

Plastics can be used as partial or full substitutes for natural aggregates (sand, gravel, and crushed stone) in concrete, primarily to address plastic waste issues and reduce the demand for virgin aggregates. However, this comes with significant trade–offs in concrete performance.
Different types of recycled plastics have been used as aggregate replacements in concrete, each with distinct characteristics affecting concrete properties. The most commonly studied and applied recycled plastics include:
- Polyethylene Terephthalate (PET): Widely sourced from plastic bottles, PET is frequently used as coarse aggregate replacement. It improves workability but tends to reduce compressive strength at higher replacement levels. PET aggregates are usually shredded and sieved to desired sizes before incorporation. Studies show optimal performance at moderate replacement levels (around 5–10%) with PET.
- High–Density Polyethylene (HDPE): Commonly derived from detergent containers and packaging, HDPE is used primarily as fine aggregate replacement. It enhances workability and can improve tensile and flexural strength at low replacement levels (around 2–4%), but excessive amounts reduce compressive strength. HDPE is lightweight and hydrophobic, affecting bonding with cement.
- Polypropylene (PP): Used in fiber form or as aggregate, PP plastic waste can improve tensile and flexural strength due to its fibrous nature, especially at low replacement levels. However, it generally reduces compressive strength when used as coarse aggregate replacement. PP aggregates increase porosity and reduce density.
- Polyvinyl Chloride (PVC): Less commonly used but studied as aggregate replacement, PVC particles tend to reduce strength and durability due to poor bonding and chemical incompatibility with cement paste. PVC is often used in shredded or granulated form.
- Low–Density Polyethylene (LDPE) and Soft Plastics: Soft plastics, including LDPE, are more challenging to incorporate due to poor bonding and flexibility. However, innovative products like aggregate made from recycled soft plastics have been developed for non–structural applications such as pathways and curbs, demonstrating durability and acoustic benefits.
- Other materials: Rubber and e–waste plastics have also been explored as partial aggregate replacements, often in specialized applications, but they are less common compared to PET, HDPE, PP, and PVC.

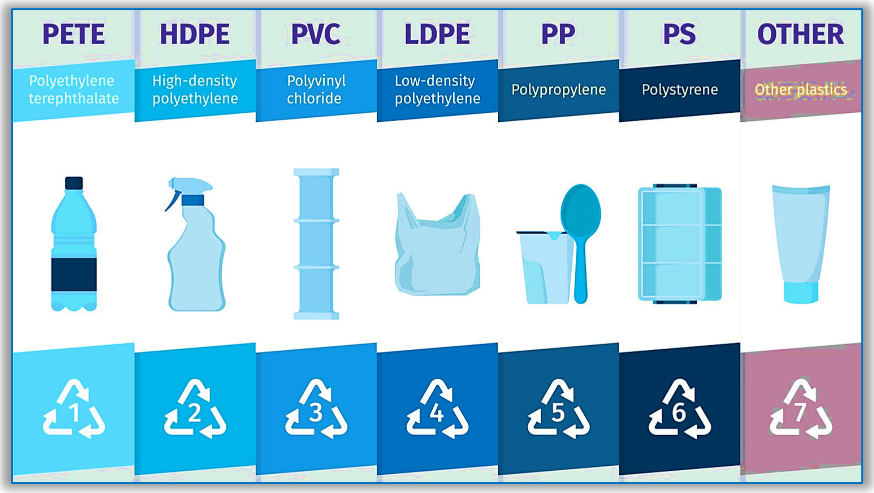

Figure 5. Types of recycled plastics

Commonly studied forms of plastic used:

- Plastic granules or pellets: Shredded and sieved plastic particles used as fine or coarse aggregates.
- Plastic fibers: Added to concrete to improve tensile strength and crack resistance.
- Plastic pellets from melting processes: Used in some applications for uniform size and shape.

Summary Table:

Plastic Type	Source	Typical Use in Concrete	Effects on Concrete Properties
PET	Bottles	Coarse aggregate replacement	Improves workability; strength decreases beyond ~10% replacement
HDPE	Detergent containers	Fine aggregate replacement	Improves tensile/flexural strength at low %; reduces compressive strength at higher %
PP	Packaging, fibers	Aggregate or fiber addition	Enhances tensile/flexural strength; reduces compressive strength
PVC	Pipes, sheets	Aggregate replacement	Generally reduces strength and durability due to poor bonding
LDPE/Soft Plastics	Bags, films	Specialized aggregates	Used for non–structural applications; challenges with bonding

PET, HDPE, LDPE, and PP are the most widely studied and used plastics in concrete applications. PET and HDPE are the most commonly used recycled plastics for aggregate replacement in concrete, offering a balance between sustainability and mechanical performance, especially at low to moderate replacement levels. Other plastics like PP and PVC are used more selectively, often with additional treatments or in fiber form to mitigate bonding and durability issues.

The form of the plastic (flakes, fibers, pellets) and the percentage used affect the mechanical properties of the concrete. Optimal replacement levels vary, but typically range from 2% to 10% by weight of aggregate for best balance of strength and durability. Mixed plastic waste can be used, but performance may vary depending on the blend and contamination.

5. GAINS & BENEFITS

Using recycled plastic as a partial replacement for aggregates in concrete offers significant SUSTAINABILITY GAINS:

- Waste reduction: Incorporating recycled plastic diverts large volumes of plastic waste (e.g., bottles, detergent containers) from landfills and the environment, addressing the global plastic pollution crisis and reducing construction and demolition waste streams.
- Lower carbon emissions: Replacing natural aggregates with recycled plastic reduces the need for energy–intensive extraction and processing of virgin materials.
- Resource conservation: Using plastic waste conserves natural resources like sand and gravel, which are becoming increasingly scarce and environmentally damaging to extract.

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- Durability and longevity: Concrete with recycled plastic aggregates benefits from the inherent durability of plastics, which are resistant to water, insects, and atmospheric degradation. This enhances the lifespan of concrete structures, reducing maintenance and replacement needs, and thus further lowering environmental impacts over time.
- Circular economy promotion: Utilizing recycled plastics in construction fosters a circular economy by turning waste into valuable building materials, encouraging innovation, job creation, and economic growth in sustainable sectors.
- Economic advantages: The durability and reduced maintenance translate into long–term cost savings, while the use of recycled materials supports sustainable development goals and environmental stewardship.

The sustainability benefits of using recycled plastic in concrete include significant waste diversion, conservation of natural aggregates, improved durability, and economic advantages, making it a compelling strategy for greener construction practices. Using plastic waste as aggregate in concrete offers several significant environmental benefits:

- Diversion of Plastic Waste from Landfills and Oceans: This approach helps mitigate the global plastic waste crisis by repurposing non–biodegradable plastics, thus reducing the volume of waste ending up in landfills and marine environments. Incorporating plastic waste into concrete diverts significant amounts of plastic from landfills and oceans, directly reducing the environmental degradation and harm to marine and terrestrial ecosystems caused by plastic pollution. Utilizing plastic waste in concrete construction lessens the volume of waste sent to landfills, helping to alleviate the burden on waste management systems and extend landfill lifespans
- Conservation of Natural Resources: By partially replacing natural aggregates (such as sand and gravel) with plastic waste, the demand for these non–renewable resources is reduced, helping to preserve natural habitats and decrease the environmental impact of aggregate extraction. By replacing a portion of natural aggregates (like sand and gravel) with plastic waste, the extraction and depletion of these non–renewable resources are reduced, preserving natural habitats and minimizing ecosystem disruption
- Enhanced Sustainability in Construction: Utilizing waste plastics in concrete promotes a circular economy, turning a problematic waste stream into a valuable resource for the construction industry and supporting sustainable building practices
- Mitigation of Environmental Pollution: By reducing the accumulation of plastic waste in the environment, this practice lessens the harmful effects of plastic pollution on terrestrial and marine ecosystems. By preventing plastic waste from accumulating in the environment, this practice reduces soil and water contamination and the associated negative impacts on wildlife and human health

Using plastic waste as aggregate in concrete contributes to reduced plastic pollution, conservation of natural resources, and enhanced sustainability of construction materials. Using plastic waste as aggregate in concrete helps minimize plastic pollution, natural resource depletion, landfill use, and environmental contamination, while also offering benefits such as improved insulation and reduced resource consumption. Therefore, the main benefits are:

- Waste Utilization: Diverts significant plastic waste from landfills and oceans.
- Resource Conservation: Reduces demand for quarrying sand and gravel, conserving natural resources and reducing landscape disruption.
- Potential Performance Enhancements: Can improve impact resistance, ductility, and freeze–thaw durability in specific applications when used appropriately.

6. KEY CONSIDERATIONS & CHALLENGES

Plastic waste can effectively replace a portion of coarse aggregates in concrete, typically up to 10–15%, balancing mechanical performance and sustainability. Proper mix design and curing are essential to optimize strength and durability. This approach supports sustainable construction by recycling plastic waste and reducing reliance on natural gravel without severely compromising concrete quality. But, several key considerations and challenges are important to be mentioned:

- significant strength reduction: Plastics generally have much lower stiffness and strength than natural aggregates. Replacing even 10–20% of coarse aggregate can lead to substantial drops in compressive and tensile strength (often 30–60% reduction). This limits use to non–structural applications (pavements, drainage layers, filler, precast blocks, insulation).
- poor bonding: The hydrophobic nature of plastics prevents good adhesion to the cement paste, creating weak interfaces that act as failure points.
- durability concerns: Plastics can be susceptible to UV degradation (if exposed) and long–term creep (slow deformation under load). Their durability within the concrete matrix over decades is still an active research area.
- workability: Plastics can alter the rheology of fresh concrete, sometimes requiring adjustments to water content or the use of admixtures.
- porosity & permeability: Plastics are often less dense than aggregates and can create more voids, increasing water permeability and reducing durability.

While plastics can be used to replace natural aggregates in concrete, it's primarily a waste management solution rather than a performance–enhancing one. Using plastics as a substitute for natural aggregates in concrete is primarily motivated by environmental concerns and waste management, rather than by a desire to enhance concrete performance. The primary benefit of using plastics as aggregates in concrete is environmental, not performance–related. While certain properties like workability and toughness can improve, overall mechanical strength tends to decrease, limiting the use of plastic aggregate concrete to non–structural or specialized applications. The practice is best viewed as a sustainable waste management solution rather than a means to enhance concrete performance. The resulting concrete is significantly weaker and less stiff, making it suitable only for non–structural applications where high strength is not critical. Careful selection of plastic type, particle size, treatment, and replacement ratio is essential. Research continues to improve bonding and performance, but widespread structural use remains limited due to the inherent property trade–offs.

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