[1.]Andrei–Mihai BACIU, [2.]Imre KISS

WASTES USED AS AGGREGATE REPLACEMENT IN CONCRETE: ENVIRONMENTAL AND RESOURCE CONSERVATION BENEFITS

[1.]University POLITEHNICA Timisoara, Doctoral School Timisoara, Timisoara, ROMANIA
[2.]University POLITEHNICA Timisoara, Faculty of Engineering Hunedoara, Department of Engineering & Management, Hunedoara, ROMANIA

Abstract: Waste materials are a major issue for environmental challenges, due to greenhouse gas emissions, reduce natural resources, demolition storage, and energy consumption and generate pollution. Of natural resources extracted throughout history, approximately 80% has been within this last century. Approximately 40% is estimated to have happened in Europe. The growing concern for sustainable construction practices has increased interest in incorporating recycled materials into concrete production. Therefore, numerous research studies conducted to explore the feasibility of utilizing waste glass, ceramics, plastics and rubber as recycled aggregates in concrete. The need to curtail the impacts of concrete on the natural environment and the engineering challenges of providing for ecologically sustainable development had previously been recognized. Concrete salvaged from construction and demolition (or C&D), as well as tires, plastics, glass or textiles, can also be recycled into aggregate. The utilization of waste as aggregates in concrete demonstrated stable and improved mechanical and durability performance. Various types of waste materials can be incorporated into concrete to improve its properties, reduce environmental impact, and promote sustainability in construction. These wastes can serve as partial replacements for cement, aggregates, or as additives/fibers. These waste materials not only enhance concrete's mechanical properties such as compressive and tensile strength, durability, and workability but also help reduce construction costs and environmental degradation by diverting waste from landfills and reducing natural resource consumption.
Keywords: natural aggregates (NA), recycled aggregates (RA), wastes, construction, concrete industry

1. INTRODUCTORY NOTES

CONCRETE is among the world's greatest–produced building materials. Concrete is a crucial component of civil infrastructure construction and the most widely utilized construction material worldwide due to its relative affordability, durability, and ease of use. Due to its low cost, the availability of its constituent elements, long–lasting sturdiness and capacity to withstand adverse weather conditions, concrete is one of the first–born and utmost widespread construction materials. The goal of the construction industry nowadays is the progress of ecological edifices by executing technological and architectural solutions, reducing the energy feeding of the building resources trade, falling personified energy and minimizing price and ecological effects. Finding eco–friendly materials for building construction is necessary because the environment inside of buildings has a significant impact. The goal of environmentally friendly material manufacturing is to produce materials that have the desirable physical and mechanical properties to be used for construction purposes and less wastage.

Concrete is the most consumed material, with three tonnes per year used for every person in the world. In addition, twice as much concrete is used in construction globally as a core material compared to all other building materials combined.

The three main components of concrete are cement, aggregate, and water. Waste materials can be utilized as fillers, fibres, or substitutes for fine aggregate in concrete. The primary component of concrete is the AGGREGATE. Typically, 70–80% of the volume of concrete is made up of aggregates, with the rest comprising water, cement, and additives. Hence, the properties and characteristics of aggregates directly influence the overall effectiveness and performance of concrete.

AGGREGATES in construction refer to granular materials like sand, gravel, crushed stone, or crushed bricks that are used as essential components in concrete, mortar, and other construction materials. They include natural substances like sand, gravel, crushed stone, and recycled materials.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Aggregates provide volume, stability, strength, and durability to the construction mixes such as concrete. Types of aggregates include:

- NATURAL AGGREGATES, derived from natural deposits like riverbeds or quarries (sand, gravel, crushed rock) and used in their natural state or after processing like crushing or washing.
- MANUFACTURED AGGREGATES, produced industrially or as by–products (e.g., slag from steel production, fly ash pellets). Sometimes are produced from processing waste materials.
- RECYCLED AGGREGATES, made from construction and demolition waste such as crushed concrete or used asphalt. Are used to reduce raw material consumption and manage waste effectively

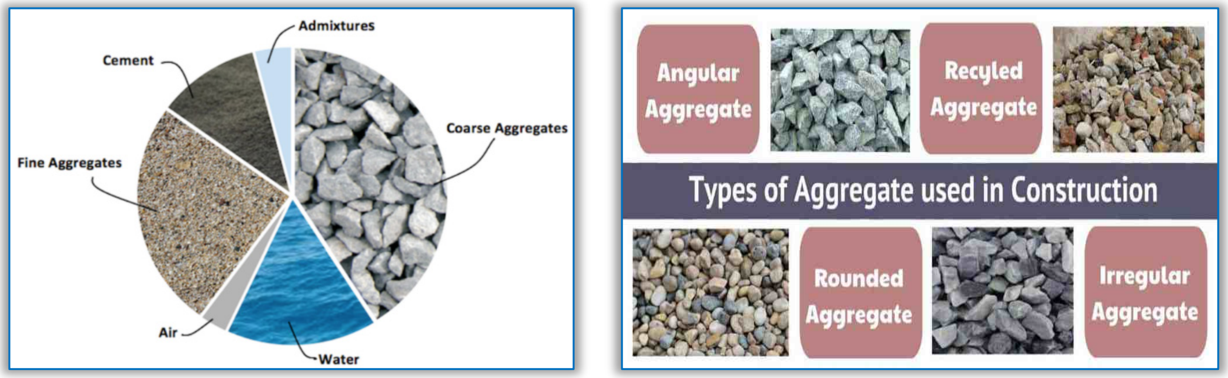

Figure 1. The concrete element and the types of aggregate used in construction

Figure 2. Construction aggregates

Various sizes and types of aggregates (natural, manufactured, recycled) allow adaptation to specific needs. Fine and coarse aggregates fill voids and increase density in concrete mixes, improving workability and cohesion. Therefore, aggregates play a fundamental role in construction by serving as the essential granular materials in concrete.

- FINE AGGREGATES play a vital role in providing the necessary workability, strength, and durability to concrete. The fine aggregate is the key component of the concrete. It makes up to 35–45% of the total volume of concrete mixture. They fill the voids between coarse aggregates and cement particles, enhancing the overall cohesion of the mixture. Fine aggregates are small–sized particles, each with a specific fine aggregate size classification, used extensively in construction. They typically consist of sand, crushed stone, or crushed slag. However, the extraction of natural aggregates, like river sand, has led to significant environmental concerns and resource depletion. The demand for sand in construction, road building, and other infrastructure projects has far exceeded the natural replenishment rate.
- COARSE AGGREGATE is crucial in the construction industry. It provides the necessary strength and durability and determines the workability of the concrete. COARSE

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

AGGREGATES are granular materials. It is often used in construction for concrete making. Its major composition includes crushed stone, gravel, or recycled concrete. Their durability depends on the quality of the coarse aggregate, significantly impacting the strength and workability of the concrete. It is obtained naturally from ground deposits of crushed stone, quarries, river gravels, etc. They can also be extracted by blasting the queries or crushing them.

CRUSHED STONE AGGREGATE comes from breaking down large rocks like granite, limestone, or basalt. The crushed pieces are usually angular and rough. This shape helps them lock together tightly in concrete and asphalt, making the final material strong and stable.

GRAVEL AGGREGATE is made up of small, rounded rocks that have been worn down naturally by water or ice and we often find it in rivers.

- ROUNDED AGGREGATES generally occur naturally. They have a rounded and smooth surface, that improves workability and helps reduce the water demand. These rounded aggregates can be easily found near the streams and riverbeds. The major source of rounded aggregates is from natural deposits.
- IRREGULAR AGGREGATES, characterized by their non–uniform shape, can decrease workability compared to rounded aggregates. Its abnormal shape is formed by friction. It is mainly composed of gravel and small stones. The irregular aggregate has a rough surface, produced by crushing the largest stones. The use of irregular aggregate started with the advent of mechanical crushing techniques.
- ANGULAR AGGREGATES is composed of sharp angular edges created by crushing large stones. The angular aggregate is popularly known for its higher interlocking capacity. This offers high strength to the concrete mix. It is composed of basalt, limestone, or granite. It improves the bonding of the cement with its rough surface texture. It comprehensively produces greater strength and stability in concrete structures with higher interlocking properties. It is used in pavement and road construction.
- FLAKY AGGREGATES are aggregates with the least dimension. Any aggregate with a thickness less than 60% of its mean dimension is classified as flaky aggregate. It is composed of different types of rocks. Its surface texture varies with the rock type.

Figure 3. Fine, coarse and recycled aggregates

- RECYCLED AGGREGATE primarily consists of materials recovered from construction and demolition waste. These materials, after being crushed and processed, can be used as a substitute for virgin aggregates in various construction applications. Common components include crushed concrete, brick, asphalt, and sometimes even reclaimed gravel.

AGGREGATE plays a crucial role in the composition and performance of concrete mix. Understanding the types, classifications, and roles of aggregate (fine or coarse) is fundamental for engineers and construction professionals to optimize concrete mix design for specific structural requirements, ensuring longevity and structural integrity.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

2. REPLACEMENT OF NATURAL AGGREGATE

With the increased consumption of concrete, this natural resource will be depleted and scarce, thus requiring another environmentally friendly replacement. Applying the concept of green buildings to the concrete industry, different alternatives could be used to reduce cement's content or natural aggregates' content and replaced by more sustainable environmentally friendly constituents.

With the ever–growing need of the world to become more sustainable, waste products are being disfavoured more and more. At present, the general waste management practices and treatment of such waste streams are incineration, recycling, or landfills (wherein the unsustainable process of landfilling is performed). However, current recycling practice is not sustainable, and landfill is still the most commonly adopted method.

Partial replacement of traditional natural aggregates is increasingly common to promote sustainability, reduce costs, and improve certain properties of construction materials. Common approaches include:

- MANUFACTURED SAND, produced by crushing rocks to replace natural sand, which conserves natural resources.
- RECYCLED AGGREGATES, using crushed concrete or demolished material as a substitute for natural aggregate reduces landfill waste.
- INDUSTRIAL BY–PRODUCTS, materials like fly ash, slag, or crushed glass can partially replace fine aggregates, improving some performance aspects or environmental impact.

Partial replacement affects the concrete or asphalt mix's workability, strength, and durability, necessitating careful adjustment in mix design (e.g., water–cement ratio) to maintain desired properties. In essence, aggregates are crucial base materials in construction, and partial replacement offers an effective way to balance sustainability, cost, and performance. Emerging innovations for sustainable aggregate replacement in construction primarily focus on reducing environmental impact, conserving natural resources, and improving material performance by substituting traditional natural aggregates with recycled materials.

Approximately 10 billion tons of fine and coarse aggregate are manufactured worldwide annually, solely to be used as concrete for constructed structures. With approximately 80% of conventional concrete comprising sand and stone, activities in their extraction and relocation harm the natural environment. Manufacturing concrete causes substantial amounts of ecological damage and energy consumption. Aggregate is traditionally produced by crushing sand and rock, the processes of which have significant impacts on the natural environment. The replacement of natural aggregate with different wastes, therefore, theoretically removes this environmental damage and energy consumption.

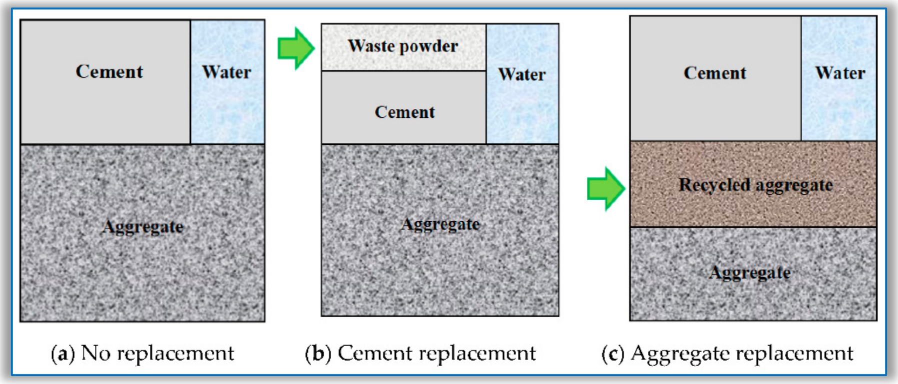

Figure 4. Replacement aggregate in concrete

The modern lifestyle, along with the new technologies caused more waste materials production for which the disposing problem exists. Most waste products are non–disposable and stay in the environment for hundreds of thousands or perhaps millions of years. Around 80% of natural aggregate extracted throughout history has happened in the last century. The increasing amount of waste that needs to be disposal of at landfills has brought renewed interest in maximizing the application of waste in concrete products. The continuous extraction of natural resources and waste has the following environmental impacts:

- the substantial energy consumption in extracting the raw material;
- the high ecological damage to mined and extracted areas;
- the fact that disposed waste glass retains its shape and does not biodegrade for centuries.

Due to the awareness of the environment and the focus on sustainable development, the construction industry is becoming more interested in utilising waste or recycled resources in concrete. In these circumstances, waste materials can be potentially utilised in concrete to improve durability and service life, lower the specific energy consumption, and utilise recycled aggregate to minimise the environmental effect of these operations to meet these demands. 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 of institutions and governments. The environmental impacts of natural aggregate extraction and the suitability of wastes as a replacement have previously been studied.

3. POLICY AND SUSTAINABILITY CONTEXT

The European Green Deal and similar initiatives emphasize reducing natural resource extraction and increasing recycled material uptake in construction, highlighting the strategic importance of recycled aggregates in meeting climate and circular economy targets. Regulatory frameworks and standards are evolving to support the safe and effective use of recycled aggregates, encouraging innovation and broader adoption in the concrete industry.

Therefore, replacing natural aggregates with various waste materials in concrete manufacturing is a multifaceted strategy that reduces environmental impact, conserves finite resources, lowers greenhouse gas emissions, and offers economic advantages. Advances in processing and mix design continue to improve recycled aggregate concrete's performance, making it a key component of sustainable construction and circular economy efforts worldwide. Non–traditional waste materials, including crushed glass and recycled plastics, are explored as aggregate substitutes to reduce environmental burdens and landfill use. These materials also create opportunities for novel concrete properties related to durability and aesthetics. In fact, sustainable aggregate replacement innovations embrace recycling, conserve natural resources, and enhance concrete performance, supporting greener construction practices globally.

Replacing natural aggregates with various waste materials in concrete manufacturing have several environmental benefits, such:

- Resource Conservation: Using recycled aggregates (RA) reduces the consumption of natural aggregates (NA), thereby decreasing quarrying activities and preserving natural habitats and riverbeds. For example, in the European Union, concrete production accounts for about 45% of all aggregates extracted, so substituting NA with RA can substantially reduce environmental degradation.
- Waste Diversion: Incorporating waste materials such as construction and demolition waste (CDW), industrial by–products, and municipal solid waste (MSW) residues into concrete diverts large volumes of waste from landfills, mitigating land use pressures and pollution risks.
- Lower Carbon Footprint: Provided the recycled aggregates are of adequate quality, recycled aggregate concrete (RAC) can have a smaller carbon footprint than natural aggregate concrete (NAC). This is due to reduced emissions from raw material extraction, processing, and transport. For instance, using recycled coarse aggregates from concrete block wastes

can reduce fossil fuel depletion by nearly 59% and global warming potential by over 85% compared to conventional concrete.

Also, several economic benefits are the:

- Cost Savings: Waste–derived aggregates often cost less than natural aggregates due to lower extraction and transportation expenses. Using recycled materials reduces disposal costs and can lower overall concrete production costs.
- Circular Economy and Industry Efficiency: The reuse of waste materials in concrete fosters industrial symbiosis and resource efficiency, supporting sustainable construction practices and potentially creating new economic opportunities in waste processing and material supply chains.

Millions of tons of waste is produced in the world each year and most of it is not recyclable. Furthermore, recycling waste consumes energy and produces pollution. In addition, accumulation of waste in the suburbs and the disposal of waste are very dangerous for the environment. Using waste material in concrete production is an appropriate method for achieving two goals: eliminating waste and adding positive properties in concrete. Since the green concrete industry is expanding, it is necessary to evaluate concrete that contains waste from all aspects in order to determine its capability.

4. TECHNICAL CONTEXT

Reusing of wastes is considered essential and important from multiple perspectives. It helps preserve and sustain non–renewable natural resources, decreases the pollution of the environment, and helps to conserve and recycle energy production processes. Wastes and industrial by–products should be viewed as potentially valuable assets awaiting appropriate treatment and application. Therefore, the incorporation of industrial waste such as waste glass or plastics as aggregate in concrete has gained significant interest in recent years. The partial replacement of natural aggregates with recycled waste materials have the following influences on:

- Mechanical properties of the new concrete: Studies show that partial replacement of natural aggregates with recycled waste materials can maintain or even improve concrete's compressive, flexural, and tensile strengths when properly processed and incorporated. Optimal replacement rates typically range between 10% and 30%, balancing sustainability with structural integrity.
- Surface treatments and admixtures: Advanced treatments such as chemical washing, mechanical abrasion, and carbonation improve recycled aggregate quality, while mineral admixtures like silica fume and fly ash enhance concrete durability and performance, enabling higher substitution levels.
- Diverse waste sources: Besides CDW, other waste streams such as industrial by–products (fly ash, slag), MSW incineration residues, plastics, glass cullet, paper fibers, and textile wastes are being explored as aggregate replacements or additives, broadening the scope of sustainable concrete materials.

Various types of waste materials can be used as replacements for fine and coarse aggregates in cement concrete, contributing to sustainability and waste reduction:

- Fine Aggregate Replacement:
- Stone waste fines: Provide better mortar properties when used as partial replacement of fine aggregate rather than cement.
- Agro–waste materials: Agricultural wastes such as groundnut shell, oyster shell, cork, rice husk ash, tobacco waste, bagasse ash, and sawdust ash have been successfully used as partial fine aggregate replacements. For example, bagasse ash and oyster shell can replace up to 20% of fine aggregate while achieving required strength. These agro–wastes can improve workability, durability, and thermal resistance of concrete.

- Construction and demolition (C&D) waste: Crushed C&D waste can partially replace fine aggregate. However, compressive strength tends to decrease with increasing replacement percentage, with about 20% replacement causing a notable strength reduction.
- Industrial waste materials: Various industrial wastes have been used as fine aggregate replacement, improving filler properties and microstructure of concrete.
- Organic wastes: Rice husk ash, wood ash, corncob granules, wheat straw, and similar organic wastes have been studied as fine aggregate substitutes, showing potential for mechanical performance and sustainability benefits.

▦ Coarse Aggregate Replacement:

- Construction and demolition waste: Recycled coarse aggregates produced from C&D waste are widely used as partial or full replacements for natural coarse aggregates. They contribute to circular economy goals but require quality control due to heterogeneous composition.
- Ceramic waste: Ceramic wastes have been effectively used as both coarse and fine aggregates in concrete production, showing potential for sustainable construction.
- Plastic waste: Waste plastics such as polyethylene (PE) and polyethylene terephthalate (PET) have been used as coarse aggregate replacements, improving workability and reducing density of concrete.

Therefore, stone waste, agro–waste (e.g., rice husk ash, bagasse ash), construction and demolition waste, ceramic waste, plastic waste, and various industrial wastes are among the types of wastes utilized as partial replacements for fine and coarse aggregates in cement concrete, each with specific effects on concrete properties and optimal replacement levels

5. DIFFERENT WASTES USED AS AGGREGATE REPLACEMENT IN CONCRETE

A variety of waste materials can be used as partial or full replacements for natural aggregates in concrete. These alternatives help reduce environmental impact, conserve natural resources, and often provide cost savings. Below are presented the main types of waste materials commonly used as aggregate replacement:

▦ Construction and Demolition Waste

- Recycled Concrete Aggregate (RCA): Produced by crushing demolished concrete structures. Used as coarse and fine aggregate in new concrete, road base, and fill.
- Recycled Mixed Aggregate (RMA): Contains a mix of concrete, brick, asphalt, and other construction debris. Often used in non–structural applications.

Figure 5. Concrete debris – Recycled Concrete Aggregate (RCA)

Figure 6. Recycled Mixed Aggregate (RMA)

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

Industrial By–products

- Blast Furnace Slag: Air–cooled or granulated blast furnace slag is a by–product of steel manufacturing used as coarse or fine aggregate.
- Fly Ash Aggregates: Manufactured from fly ash, a residue from coal combustion, these aggregates are lightweight and suitable for various concrete applications.
- Steel Slag: Produced from steel–making processes, it can be used as a substitute for natural aggregates.

Figure 7. Industrial By–products

Municipal Solid Waste (MSW) Fractions

- Incinerator Bottom Ash (IBA): Residue from municipal solid waste incineration, used as coarse aggregate after proper treatment to remove harmful substances.
- Glass Cullet: Crushed waste glass is used as a fine aggregate replacement, improving aesthetics and sometimes mechanical properties.
- Plastics: Shredded or ground plastic waste can partially replace fine or coarse aggregates, often resulting in lightweight concrete.
- Paper and Cardboard Fibers: Used as fillers or partial aggregate replacements, improving insulation and reducing cement use.

Figure 8. Degradable, partial degradable and non–degradable Municipal Solid Waste (MSW) Fractions

Figure 9. Organic and Agricultural Wastes

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

- Organic and Agricultural Wastes
  - Rice Husk Ash and Wood Ash: These ashes are suitable as aggregate replacers, especially for lightweight concrete, and can enhance certain mechanical properties.
  - Expanded Polystyrene (EPS): Waste EPS is used to produce lightweight aggregate for non–structural concrete applications.
- Other Waste Streams
  - Ceramic Waste: Crushed ceramics, such as tiles and sanitary ware, are used as aggregate replacement, especially in mortar and non–structural concrete.
  - E–waste (Electronic Waste): Certain e–waste fractions, after processing, have been explored as aggregate substitutes in limited applications.
  - Foundry Sand: Used foundry sand from metal casting industries serves as a fine aggregate replacement.
  - Crushed Bricks and Blocks: Broken bricks and blocks from demolition are used as coarse or fine aggregate.

Summary Table: Waste types and their use as aggregate replacement

Waste Type	Aggregate Replaced	Typical Application
Recycled concrete (RCA)	coarse & fine aggregate	structural & non–structural concrete
Mixed construction waste (RMA)	coarse & fine aggregate	non–structural, road base
Blast furnace/steel slag	coarse & fine aggregate	structural concrete, road base
Fly ash aggregates	lightweight aggregate	lightweight concrete
Incinerator bottom ash (IBA)	coarse aggregate	concrete, masonry units
Glass cullet	fine aggregate	decorative, structural concrete
Plastics	fine/coarse aggregate	lightweight, non–structural concrete
Paper/cardboard fibers	filler, fine aggregate	insulating concrete, blocks
Rice husk/wood ash	fine aggregate	lightweight, eco–concrete
Expanded polystyrene (EPS)	lightweight aggregate	insulating, lightweight concrete
Ceramic waste	fine/coarse aggregate	mortar, non–structural concrete
E–waste	coarse aggregate	experimental, limited use
Foundry sand	fine aggregate	concrete, road base
Crushed bricks/blocks	coarse/fine aggregate	pavements, non–structural concrete

Figure 10. Waste types

Therefore, a variety of waste materials can be used as partial or full replacements for natural aggregates in concrete, offering significant environmental, economic, and technical benefits. This

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

practice contributes directly to the circular economy by transforming waste into valuable secondary raw materials, reducing the extraction of virgin mineral resources, and lowering the overall carbon footprint of concrete production. Using these waste materials as aggregate replacements in concrete not only diverts waste from landfills but also supports sustainable construction and the circular economy. Proper processing and quality control are essential to ensure safety, durability, and performance of the resulting concrete.

6. REPLACING NATURAL AGGREGATES WITH INDUSTRIAL OR ORGANIC WASTE MATERIALS IN CONCRETE

Agricultural waste is investigated as a possible sand replacement, given its abundance and the necessity to treat it. Incorporating organic waste materials in concrete mixtures not only provides a practical solution to replace conventional aggregates, but also alleviates the environmental and financial challenges associated with waste disposal in a circular economy perspective.

Figure 11. Organic waste materials (examples)

This solution offers significant environmental benefits:

- Reduction in natural resource extraction: Using recycled aggregates from construction and demolition waste (C&DW) or industrial by–products reduces the demand for virgin aggregates, preserving natural landscapes and reducing quarrying impacts.
- Lower carbon emissions: Recycling aggregates locally cuts down emissions associated with transportation and quarrying. Studies show reductions in CO_2 emissions up to about 20% or more compared to traditional concrete.
- Waste diversion from landfills: Large volumes of C&DW and organic wastes are diverted from landfills, reducing environmental pollution and landfill space usage. For example, about 1.5 billion tons of C&DW are generated annually, much of which can be reused as recycled aggregates.
- Energy savings: Production of recycled aggregates typically consumes less energy than mining and processing natural aggregates, contributing to lower overall energy use in concrete production.
- Carbon sequestration potential: Organic waste–based aggregates (e.g., rice husk ash, wood ash) can store biogenic carbon, partially offsetting greenhouse gas emissions and contributing to climate change mitigation.
- Support for circular economy: Incorporating waste materials into concrete promotes resource efficiency and circularity by giving value to waste streams and reducing reliance on finite resources.
- Reduced environmental footprint: Life cycle assessments show that concrete with recycled or organic waste aggregates can have similar or lower global warming potential compared to conventional concrete, especially when accounting for carbon capture and reduced raw material extraction.

Therefore, replacing natural aggregates with industrial or organic wastes in concrete helps conserve natural resources, reduce greenhouse gas emissions, lower energy consumption, minimize landfill disposal, and foster sustainable construction practices.

Local recycling of waste aggregates is crucial for maximizing environmental benefits because:

- Significantly reduces transportation emissions: Recycling aggregates near the source minimizes the need for long-distance hauling, which cuts down fuel consumption and associated carbon dioxide emissions.
- Lowers overall carbon footprint: Local processing of recycled materials requires less energy compared to quarrying and refining virgin aggregates, further reducing greenhouse gas emissions by up to 40% when recycled aggregates replace traditional ones.
- Decreases landfill use and related pollution: By recycling waste aggregates locally, large volumes of construction and demolition waste are diverted from landfills, reducing landfill space demand and methane emissions from decomposing waste.
- Conserves natural resources and ecosystems: Local recycling reduces the need for quarrying virgin aggregates, which often scars landscapes and disrupts ecosystems, preserving biodiversity and natural habitats.
- Supports circular economy and community resilience: Keeping recycling within the local area fosters resource efficiency, creates local jobs, and strengthens economic resilience by reducing dependence on external supply chains.

In essence, local recycling of waste aggregates enhances environmental sustainability by cutting emissions, conserving resources, reducing landfill impacts, and promoting economic and ecological benefits within communities.

7. REPLACING NATURAL AGGREGATES WITH GLASS, PLASTIC AND TEXTILE WASTES

Glass, plastic, and textile wastes can be incorporated into concrete in the several ways. Extensive research has been conducted during the past three decades to include waste plastic, rubber and glass in concrete. Recent interest to include these materials in concrete can be ascribed to the growing need for innovative waste disposal, as well as to minimise raw material usage.

REPLACING NATURAL AGGREGATES WITH GLASS WASTE

The use of GLASS WASTE as a partial replacement for both fine and coarse aggregates in concrete is of growing interest due to environmental and economic benefits. The reuse of glass waste in concrete helps reduce environmental burdens from both sand/gravel extraction and glass landfill.

Figure 12. Glass waste

Glass waste is versatile, used as fine/coarse aggregate or cement replacement, enhancing strength and durability:

- Fine aggregate replacement: Crushed waste glass can replace natural sand partially or fully as fine aggregate. It improves compressive, tensile, and flexural strengths due to its angular particle shape. However, excessive glass content may cause alkali-silica reaction (ASR), which can be mitigated by using supplementary cementitious materials like fly ash or ground granulated blast furnace slag (GGBS).
- Coarse aggregate replacement: Waste glass can also replace coarse aggregates up to 30% by weight, maintaining comparable strength and durability to normal concrete.
- Cement replacement: Finely ground glass powder acts as a pozzolanic material, improving mechanical and durability properties when used at 10–20% replacement level of cement.

- Durability aspects: Glass aggregate concrete can exhibit improved chemical resistance, freeze–thaw resistance, and elevated temperature resistance.

GLASS WASTE can successfully replace a portion of fine and coarse aggregates, especially in non–structural or lightly loaded structural applications. For best results, stay within 10–30% replacement for each fraction. This demonstrates glass waste's potential for sustainable concrete production, with clear mechanical, environmental, and economic benefits when used appropriately.

Using glass as a coarse aggregate in concrete offers several environmental advantages compared to traditional natural aggregates such as gravel or crushed stone:

- Minimizing landfill waste: Incorporating glass waste into concrete diverts a substantial volume of glass from landfill, addressing solid waste management challenges and environmental pollution caused by glass disposal.
- Sustainable raw material utilization: By integrating recycled glass, concrete manufacturing becomes more sustainable, aligning with green building practices and policies encouraging reduced environmental impact and greater material circularity
- Reduced resource extraction: Utilizing waste glass diminishes the need for quarrying and extraction of natural stone, helping conserve finite natural resources and limit landscape disturbance, habitat loss, and ecosystem impacts

Using glass as a coarse aggregate represents a significant step toward eco–friendly and sustainable construction materials, offering both environmental and economic gains when carefully implemented. Glass waste in concrete is increasingly recognized as a sustainable alternative material that offers significant environmental and technical benefits. It can be used either as a partial replacement for aggregates (both fine and coarse) or as a supplementary cementitious material (SCM) in powdered form, providing versatility in concrete production.

Using glass waste aligns with circular economy principles by keeping materials in use longer and reducing environmental externalities. In essence, glass waste in concrete contributes to sustainable construction by reducing landfill waste and carbon emissions, conserving natural aggregates, and enhancing durability when properly incorporated. Optimal use typically involves partial replacement (up to about 30%) of natural aggregates or cement, balancing environmental gains and mechanical performance.

REPLACING NATURAL AGGREGATES WITH PLASTIC WASTE

Humans are consuming vast quantities of plastic across various types, leading to significant challenges in decomposition and the subsequent generation of extensive plastic waste, posing a significant threat to the environment. To address this issue, researchers are actively exploring methods to minimize plastic waste and mitigate its widespread impact by incorporating it into concrete. This not only enhances concrete's durability but also reduces costs.

Figure 13. Plastic waste

Plastic wastes can be used in concrete mixtures in two ways: plastic fibers (PF) and plastic aggregate (PA). In concrete mixtures, plastic waste as aggregates are utilized to partially replacement of natural fine aggregate (NFA) or natural coarse aggregate (NCA). Waste plastic aggregates are typically utilized to manufacture lightweight concrete because they have a lesser bulk density as compare to natural aggregates. The utilization of recycled waste plastic in the formation of concrete was broadly investigated. The different studies in the literature that have explored the use of waste plastic aggregate (WPA) as a replacement of natural fine aggregate (NFA) and natural coarse aggregate (NCA) in cement concrete have largely focused on its impact on mechanical properties. Polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyethylene (PE), polyolefins (PO) and Poly (methyl methacrylate) (PMME) are the main sources of plastic waste. Plastic waste mainly replaces coarse aggregates or acts as fiber reinforcement, improving workability and sustainability but may reduce strength at high content.

- Aggregate replacement: Shredded or granulated plastic waste (e.g., PET, polyethylene) can partially replace coarse aggregates, reducing concrete density and improving workability. However, plastic aggregates typically lower compressive strength, so replacement levels are usually limited to maintain structural performance.
- Fiber reinforcement: Plastic fibers from recycled textiles or packaging can be added to concrete to enhance tensile strength, ductility, and crack resistance.
- Sustainability benefit: Using plastic waste reduces landfill and environmental pollution and conserves natural aggregates.

One of the most universally used materials in construction industries is concrete because of its accessibility, affordability, extended lifespan and resistance to damage against unfavourable weather conditions. However, there is a massive depletion of valuable natural resources for the concrete production. Further, plastic consumption as well as waste generation is increasing day by day which is very much challenging to be managed as it is non–biodegradable and creates various environmental pollution. Non–conventional materials such as plastic are gaining traction as a solution to these problems, and their introduction into the construction industry is becoming a widely considered trend to pursue sustainable development. Thus, the usage of plastic waste as a fractional substitution of natural aggregates in construction industry may mitigate the problems.

REPLACING NATURAL AGGREGATES WITH TEXTILE WASTE

The textile industry is classified as one of the industrial activities that currently generates the highest volume of waste. Proper management of textile waste, particularly post–industrial clippings and unsold garments, is crucial to reduce the environmental impact of the sector. Among the wide range of products, materials, and uses that this sector encompasses, used clothing (post–consumer waste) is the type of textile waste that has the greatest environmental impact. However, there is another flow of textile waste that adds tons to the waste generated by used clothing, and that is the unused clothing, meaning garments that never made it to a wardrobe, that no one has ever worn because they were never sold (pre–consumer waste). Post–industrial textile clippings, which result from the garment manufacturing process, and unsold garments that end up being incinerated, contribute to the textile industry's reputation as one of the most polluting and unsustainable sectors.

Textile waste is primarily used as fiber reinforcement to improve tensile properties and crack resistance.

- Fiber reinforcement: Recycled textile fibers (natural or synthetic) can be incorporated as microfibers in concrete to improve tensile strength, toughness, and crack control.
- Aggregate replacement: Some studies explore shredded textile waste as partial fine aggregate replacement, though this is less common and requires careful evaluation of durability and mechanical effects.
- Environmental impact: Using textile waste in concrete diverts large volumes of non–biodegradable waste from landfills.

Figure 14. Textile waste

These approaches contribute to sustainable construction by recycling waste materials, reducing natural resource consumption, and minimizing environmental impact

8. CONCLUSIONS & RECOMMENDATION FOR FUTURE RESEARCH

Recycled aggregates contribute to reducing the depletion of riverbed resources primarily by substituting natural aggregates (NA) extracted from riverbeds, quarries, and other natural deposits with recycled materials derived from construction, demolition, and other waste streams. This substitution has several important environmental and resource conservation benefits:

- Decreased Extraction of Natural Resources: By replacing natural aggregates with recycled aggregates (RA), the demand for quarrying and dredging activities in riverbeds is reduced. This leads to less disturbance of aquatic ecosystems, reduced landscape scarring, and preservation of biodiversity associated with riverine and quarry environments.
- Lower Environmental Impact: The extraction of natural aggregates is energy–intensive and generates significant carbon emissions. Using recycled aggregates reduces the need for these operations, thereby lowering greenhouse gas emissions and the overall carbon footprint of concrete production.
- Waste Diversion and Circular Economy: Recycling construction and demolition waste into aggregates diverts large volumes of waste from landfills, turning waste into a resource and promoting circular economy principles. This reduces pressure on natural aggregate sources by making better use of existing materials.
- Local Sourcing and Reduced Transportation: Recycled aggregates are often sourced locally from demolition sites or recycling plants, reducing transportation distances compared to virgin aggregates typically extracted from distant quarries or riverbeds. This further decreases fuel consumption and emissions associated with material haulage.
- Sustainability Alignment: The European Green Deal and similar policies emphasize reducing natural resource extraction, including aggregates from riverbeds. Increasing recycled aggregate use aligns with these sustainability goals by conserving finite mineral resources and supporting more sustainable construction practices.

Therefore, by substituting natural aggregates with recycled aggregates, the concrete and construction industries significantly reduce the depletion of riverbed resources, mitigate environmental damage, and contribute to sustainable resource management. This approach preserves natural habitats, lowers carbon emissions, and supports circular economy models in construction.

Based on the existing research and limitations identified, several recommendations for future research in the field of waste as aggregate in concrete can be made:

- Further investigation into the optimal percentage of replacement: Conduct studies to determine the optimum replacement percentage of waste that maximizes both the mechanical properties and sustainability aspects of concrete.

- Long–term durability assessment: Conduct long–term durability studies to evaluate the performance of concrete incorporating various wastes as aggregates under various environmental conditions, including freeze–thaw cycles, chemical exposure, and ageing effects.

Replacing conventional aggregates in concrete with various waste materials has become increasingly important in sustainable construction. This approach addresses both the environmental and economic challenges posed by the depletion of natural resources and the accumulation of waste. Many waste–derived aggregates can provide similar or even improved mechanical properties—such as compressive strength, durability, and resilience—depending on mix design and treatment. While the use of waste as aggregate replacement offers clear advantages, challenges remain:

- Variability in material properties (depending on the source and treatment of waste materials) may affect workability and concrete performance.
- Lower workability is sometimes observed, particularly with certain types of industrial or organic waste.
- Requirements for additional processing or treatments (e.g., washing, grading, or surface modification) to ensure consistency and quality

Concrete may be one solution to combat waste pollution on land, water, infrastructure and ecosystems. Moreover, alternatives to – and the reuse of – current materials are essential. Therefore, the replacement of conventional aggregate in concrete mixtures with various waste has great environmental potential. This basic idea could lead to an effective waste management solution for wastes and effectively increase the sustainable procurement of aggregates for concrete, meeting material reuse targets. This integration supports eco–friendly building practices and circular economy goals by transforming waste into valuable construction material. Using waste in place of natural aggregates in concrete is fundamentally important in construction due to its substantial environmental, economic, and technical benefits. It allows the industry to move toward more responsible, circular practices while producing concrete with properties suitable for a wide range of modern construction applications.

References

[1] Tavakoli, D., Hashempour, M., Heidari, A. (2018). Use of waste materials in concrete: A review. Pertanika J. Sci. Technol, 26(2), 499–522.
[2] Ismail, Z. Z., & Al–Hashmi, E. A. (2008). Use of waste plastic in concrete mixture as aggregate replacement. Waste management, 28(11), 2041–2047.
[3] Ismail, Z. Z., & Al–Hashmi, E. A. (2009). Recycling of waste glass as a partial replacement for fine aggregate in concrete. Waste management, 29(2), 655–659.
[4] Silva, F. A., Delgado, J. M., Azevedo, A. C., Lima, A. G., Vieira, C. S. (2021). Preliminary analysis of the use of construction waste to replace conventional aggregates in concrete. Buildings, 11(3), 81.
[5] Batayneh, M., Marie, I., Asi, I. (2007). Use of selected waste materials in concrete mixes. Waste management, 27(12), 1870–1876.
[6] Abdallah, S., Fan, M. (2014). Characteristics of concrete with waste glass as fine aggregate replacement. Int. J. Eng. Tech. Res, 2(6), 11–17.
[7] Bertoldo, N., Qureshi, T., Simpkins, D., Arrigoni, A., Dotelli, G. (2023). Concrete with organic waste materials as aggregate replacement. Applied Sciences, 14(1), 108.
[8] Sambhaji, P. P. (2016). Use of waste plastic in concrete mixture as aggregate replacement. International Journal of Advanced Engineering Research and Science, 3(12), 115–118.
[9] Prusty, J. K., Patro, S. K., Basarkar, S. S. (2016). Concrete using agro–waste as fine aggregate for sustainable built environment–A review. International Journal of Sustainable Built Environment, 5(2), 312–333.
[10] Dosho, Y. (2007). Development of a sustainable concrete waste recycling system–Application of recycled aggregate concrete produced by aggregate replacing method. Journal of advanced concrete technology, 5(1), 27–42.
[11] Hebhoub, H., Aoun, H., Belachia, M., Houari, H., Ghorbel, E. (2011). Use of waste marble aggregates in concrete. Construction and Building Materials, 25(3), 1167–1171.
[12] Adekunle, A. A., Abimbola, K. R., Familusi, A. O. (2017). Utilization of construction waste tiles as a replacement for fine aggregates in concrete. Engineering, Technology & Applied Science Research, 7(5), 1930–1933.
[13] Mo, K. H., Thomas, B. S., Yap, S. P., Abutaha, F., Tan, C. G. (2020). Viability of agricultural wastes as substitute of natural aggregate in concrete: A review on the durability–related properties. Journal of Cleaner Production, 275, 123062.
[14] Günçan, N. F. (1995). Using waste concrete as aggregate. Cement and concrete research, 25(7), 1385–1390.

[15] Shafigh, P., Mahmud, H. B., Jumaat, M. Z., Zargar, M. (2014). Agricultural wastes as aggregate in concrete mixtures–A review. Construction and Building Materials, 53, 110–117.
[16] Gautam, S. P., Srivastava, V., Agarwal, V. C. (2012). Use of glass wastes as fine aggregate in Concrete. J. Acad. Indus. Res, 1(6), 320–322.
[17] Zimbili, O., Salim, W., Ndambuki, M. (2014). A review on the usage of ceramic wastes in concrete production. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, 8(1), 91–95.
[18] Collivignarelli, M. C., Cillari, G., Ricciardi, P., Miino, M. C., Torretta, V., Rada, E. C., Abbà, A. (2020). The production of sustainable concrete with the use of alternative aggregates: A review. Sustainability, 12(19), 7903.
[19] Meng, Y., Ling, T. C., Mo, K. H. (2018). Recycling of wastes for value–added applications in concrete blocks: An overview. Resources, Conservation and Recycling, 138, 298–312.
[20] Sonawane, T. R., Pimplikar, S. S. (2013). Use of recycled aggregate concrete. IOSR Journal of Mechanical and Civil Engineering, 52(59).
[21] Raman, J. V. M., Sriram, M. (2017). Study on replacement level of concrete waste as fine aggregate in concrete. Int. J. Res. Appl. Sci. Eng. Technol, 5, 241–246.
[22] Kaish, A. B. M. A., Odimegwu, T. C., Zakaria, I., Abood, M. M. (2021). Effects of different industrial waste materials as partial replacement of fine aggregate on strength and microstructure properties of concrete. Journal of Building Engineering, 35, 102092.
[23] Rao, A., Jha, K. N., Misra, S. (2007). Use of aggregates from recycled construction and demolition waste in concrete. Resources, conservation and Recycling, 50(1), 71–81.
[24] Jaivignesh, B., Sofi, A. (2017, July). Study on mechanical properties of concrete using plastic waste as an aggregate. In IOP Conference Series: Earth and Environmental Science (Vol. 80, No. 1, p. 012016). IOP Publishing.
[25] Kishore, K., Gupta, N. (2020). Application of domestic & industrial waste materials in concrete: A review. Materials Today: Proceedings, 26, 2926–2931.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665