A Review on the Recycling Waste Materials for Green Concrete

Abhay Kumar Jha
Professor, Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India

R.S. Parihar
Professor, Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India

Varsha Lodhi
M.tech scholar, Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India

Rajesh Misra
Assistant professor, Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India

Barun Kumar
Assistant professor, Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India

Ashutosh Udeniya
Assistant professor, Civil Engineering Department, Lakshmi Narain College of Technology, Bhopal, India

ABSTRACT:
This has increased the generation of solid waste, creating environmental and economic problems on an international scale. The construction industry, one of the major environmental degrading and resource-consuming industries, plays a major role. This study examines how waste material is used in green concrete as a sustainable solution to minimize environmental burdens and save natural resources. Utilizing waste material such as silica fume, fly ash, recycled aggregates, and ground-granulated slag from blast furnaces (GGBFS), recycled plastic, and biopolymers, green concrete minimizes carbon emissions as well as reduces the need for virgin materials. In this paper, it is discussed how the application of such waste products in green concrete minimizes the carbon footprint and saves natural resources, whereas on the other hand, it also saves material and construction costs. Life cycle assessment studies and sustainability analysis give a valuable comparison in overall sustainability between green concrete and conventional concrete. Challenges and future directions in this field elucidate the uniformity of waste material quality, regulatory support, and public acceptance. The scope of further research lies in the development of material characterization, long-term durability studies, and technological advancement, which promise to deliver desired performance and applications of green concrete.

Keywords: GGBFS, Rice Husk Ash, Silica Fume, Carbon Footprint, Recycled Aggregates, Fly Ash.

INTRODUCTION

With the exponential growth in population, countries across the globe are faced with continual growth of different kinds of waste [1]. Only 37 million tons, or 55%, of the trash generated in developed nations like Australia in 2016–17 was recycled [2]. Conversely, it has been stated that Beijing, one of the largest cities in China, mixes 25,000 tons of trash every day [3]. The primary sources of these waste products are construction and demolition trash, business and industrial garbage, and home waste [4]. Even though most of these waste products may be recycled, most of them are dumped in landfills, which has detrimental effects on the environment as well as social and economic ramifications. Reuse, disposal, and efficient management are essential for resolving the central problem of waste creation. The construction industry is one of the foremost contributors to environmental impacts and a substantial resource consumer. Throughout the entire life cycle, starting from material acquisition to their end-of-life, a built structure is responsible for significant energy consumption and carbon emissions [5]. The use of virgin materials in building is mostly to blame for this. The use of virgin materials in building is mostly to blame for this. Research has indicated that materials account for around 15% of a building's energy use and carbon emissions [6]. Furthermore, using too many virgin resources to make construction materials uses natural resources and adds to the environmental load [7]. Thus, substituting waste products for virgin resources takes care of the two main problems—excessive waste production and the use of virgin materials.

With the advances of civilization, specifically because of global climate change, the retrogradation of infrastructure has become progressively challenging and one of the prime considerations of contemporary civil engineering. Across the globe, concrete continues to be the primary, unaltered building material. In order to address the problems caused by incomplete constitutional decay, concrete's durability needs to be guaranteed. In order to address the growing need for infrastructure deterioration over time, the durability characteristics of mortar should be carefully taken into account in addition to feasibility and strength, that are still the primary goals of mortar quality control and concrete mixture patterns [8]. Moreover, the massive production and use of cement, which is the main binding part of the concrete, poses some significant environmental risk. The third major source of anthropogenic carbon dioxide (CO2) emissions is cement manufacturing, which comes after the use of fossil fuels and land-use reform due to deforestation. Due to resource limitations, sustainability trends have picked up speed recently, creating a wider range of emerging operational, strategic, and management issues. By raising people’s standard of living, the building sector also makes a substantial contribution to meeting societal demands. However, this sector generates 45–65% of the garbage that is dumped in landfills, which accounts for 35% of the world’s CO2 emissions. Additionally, the various activities of construction generate significant amounts of toxic emissions, accounting for nearly 30% of greenhouse gases [9].

TYPES OF MATERIALS IN CONCRETE

Green concrete, also known as eco-friendly concrete, utilizes waste materials to reduce environmental impact and promote sustainability. Examples of some common green concrete materials include the following:

Fly Ash

Fly ash is derived from a byproduct of coal combustion in thermal electric power plants and is used to replace cement in concrete mixes, thereby reducing the consumption of virgin materials and carbon emissions. The global demand of energy is continuously increasing day to day, and it almost 50% has been increased up to 2040 [10]. In India, industrialization and population growth will primarily create the need for energy, using coal because it has a significant energy source and is expected to remain in the future. However, the energy generation in thermal power plants generally using combustion of the pulverized coal. During combustion, the volatile matter and some coal impurities are fuses, and some of them are remain suspended in the bottom of the chamber. Together with the exhaust gas and the injected particle materials—mostly spherical particles known as fly ash—all fused particles are transferred.
GGBFS (Ground Granulated Blast Furnace Slag)

An offshoot of the iron manufacturing process, it is used as a supplementary cementitious material in concrete and offers better durability and reduced environmental impact. The amount of waste dumped in lakes and landfills may be significantly decreased by using waste from industry as cementitious material instead of cement, so alleviating the environmental issues associated with cement production. In terms of durability, mechanical qualities, and thermal actions, ground-granulated blast-furnace slag (GGBS) outlines a sensible path toward the creation of sustainable cement and concrete. In addition to its positive effects on the environment, GGBS's substitution of cement shows how to effectively lessen its economic impact. Even though GGBS use in concrete production is a focus of many researchers, information in this area is fragmented, and further study is required to clarify the links among a wide range of important concerns and to more precisely ascertain these initial results [11]. The purpose of this study is to provide some clarification on the scientific research about the application and efficacy of GGBS as a cement substitute. First and foremost, a full discussion of the fundamentals of GGBS manufacture, including its heat of hydration, physical, chemical, and hydraulic activity, is provided. The qualities of newly mixed concrete, such fluidity and mechanical rigidity, are inspected in the next phase. In addition, the durability of concrete is examined and evaluated in terms of its density, carbonation depth, permeability, acid resistance, depth, and dry shrinkage. Given that GGBS demonstrates the creditworthiness of being partially integrated and, generally, presents a substitute to Ordinary Portland Cement (OPC), it may be concluded that its chemical structure is similar to that of cement. Based on these modifications, concrete containing GGBS has demonstrated a somewhat increased mechanical strength; yet, the concrete's flowability has decreased. Furthermore, it has been demonstrated that concrete incorporating GGBS cement is more durable.

Recycled Aggregates

Aggregates in the form of crushed concrete or masonry rubble are used, thereby reducing the demand for virgin natural resources and waste otherwise destined for landfill. The producing process of RAs has not significantly changed during the past several decades, even though the CDW recycling facilities has been upgraded. There are mainly two sorts of CDW recycling facilities, i.e. stationary and mobile facilities. For stationary facilities, CDW needs to be transported to the facility and processed. The stationary facilities have higher handling capacity and produce RA with better quality compared with the mobile facilities. The mobile facility, in contrast, can process the CDW on sites, so that the recycled aggregates can be reused for new construction directly without additional transportation [12].

Rice Husk Ash

RHA can be used to partially replace the cementitious material in the mixture of concrete. It can also make the concrete stronger and reduce greenhouse gas emissions. Rice husk ash has many applications because of its numerous properties [13]. It is a wonderful insulator and has applications in industrial processes that include steel foundries and the manufacturing of insulation for houses and refractory bricks. It is an active pozzolan and has numerous packages in the cement and concrete industry [14]. It is also exceedingly absorbent and is used to absorb oil on difficult surfaces, and potentially to filter arsenic from water [15]. To produce RHA, open field burning or controlled incineration of rice husks can be applied [16]. The amorphous silica and carbon content of RHA are dependent on the time and temperature of the incineration. Well-burned and well-ground RHA is very active and greatly improves the strength and durability of cement and concrete. This pozzolanic material with good and consistent properties can only be obtained by burning the rice husks under precisely defined conditions. Therefore, the type of silica formed after rice husk combustion is determined by the temperature and duration of the process. According to the literature, burning rice husks at temperatures ranging from 400 ºC to 1100 ºC produces RHA with high pozzolanic activity that remains in the amorphous or crystalline silica form [17].

Silica Fume

It is a by-product in the manufacturing of silicon metal or ferrosilicon alloy. Silica fume is a pozzolanic material that enhances the properties of concrete in terms of strength and durability. The fine particle size of silica fume allows it to act as a filler and improve packing as it enters the spaces between
particles of cement. The replacement of cement with silica fume in small portions can be feasible due to the high reactivity of silica fume with calcium hydroxide that is produced during the hydration of Portland cement. It is an ultrafine powder also known as micro silica having 75% or more silicon content containing non-crystalline silica in the range of 85–95%. The type of alloy produced in the production unit is related to the amount of SiO2 content present in silica fume [18]. The requirement of water increases for the concretes having silica fume due to its ultra-fineness; therefore, superplasticizers are used to achieve required workability. Incorporation of silica fume to concrete mixtures could result in lower bleeding, lower porosity as well as permeability because oxides of silica fume react with and consume Ca(OH)2 that is CH produced by the hydration of cement. The pozzolanic reactions would result in strength development, lower heat liberation, small pore size distribution, and lime-consuming activity. The pozzolanic properties of silica fume and its physical filling effect makes it widely acceptable supplementary cementitious material.

**Recycled Plastic**

Shredded plastic waste can be used in concrete mixtures to improve properties, such as ductility, and reduce the usage of conventional aggregates in concrete. Among the diverse types of recycling management approaches, the reuse of plastic waste in the construction industry is considered an ideal method for disposing plastic waste. By this method, recycled plastics can be reused without degradation in quality during the service cycle, and more importantly, the recycled plastics substitute the use of virgin construction materials. The use of recycled plastic materials in cementitious composite has been researched extensively. Plastics were used in concrete mainly in forms: plastic aggregates (PA), which replaced natural aggregates, the properties of fresh and hardened concrete incorporating plastic materials [19]. The impact of recycled waste plastic and rubber as aggregate on the fresh and hardened properties of cementitious composites. Moreover, the durability, functional, and microstructural properties, as well as sustainability aspects and potential applications of cementitious materials containing waste plastic and rubber in civil engineering construction, are addressed [20].

**Biopolymers**

Natural or synthetic biopolymers can be added to concrete to improve workability, reduce water usage, and enhance durability. The natural additives presented in this review include principally biopolymers, mainly by-products and waste from agriculture and industrial production that can be promising additives for earth stabilization [21]. The use of fibers, included in the biopolymers group, mainly as a polysaccharide (cellulose) or keratin (protein), is discussed separately, to evidence their specific function. Biopolymers are produced from living beings and they can have very different features: plant or animal origin, hydrophilic, hydrophobic, or amphiphilic behavior. As [22] suggest a possible classification of biopolymers includes polysaccharides, proteins, lipids, and other complex molecules.

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Properties</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash</td>
<td>Byproduct of coal combustion; reduces cement consumption and carbon emissions.</td>
<td>Supplementary cementitious material</td>
<td>Replacement for cement in concrete mixes</td>
</tr>
<tr>
<td>GGBFS</td>
<td>Byproduct of iron manufacturing; offers durability and reduced environmental impact.</td>
<td>Substitute for cement; improves strength &amp; durability</td>
<td>Supplementary cementitious material in concrete mixes</td>
</tr>
<tr>
<td>Recycled</td>
<td>Crushed concrete or masonry rubble; reduces demand for natural resources and landfill waste.</td>
<td>Recycled material for aggregates</td>
<td>Replacement for natural aggregates in concrete mixes</td>
</tr>
<tr>
<td>Aggregates</td>
<td></td>
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<tr>
<td>Rice Husk Ash</td>
<td>Byproduct of rice husk combustion; strengthens concrete and reduces greenhouse gas emissions.</td>
<td>Pozzolanic material; improves strength &amp; durability</td>
<td>Partial replacement for cementitious material in concrete mixes</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>Byproduct of silicon metal or ferrosilicon alloy manufacturing; enhances concrete strength &amp; durability.</td>
<td>Ultrafine powder; improves packing &amp; reduces porosity</td>
<td>Supplementary cementitious material for strength &amp; durability enhancement</td>
</tr>
<tr>
<td>Recycled Plastic</td>
<td>Shredded plastic waste; improves ductility and reduces the use of conventional aggregates in concrete.</td>
<td>Recycled plastic aggregates</td>
<td>Replacement for natural aggregates; improves ductility and sustainability</td>
</tr>
<tr>
<td>Biopolymers</td>
<td>Natural or synthetic biopolymers; improve workability, reduce water usage, and enhance durability.</td>
<td>Plant or animal origin; hydrophilic or hydrophobic</td>
<td>Additive for improving concrete properties such as workability and durability</td>
</tr>
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### ENVIRONMENTAL AND ECONOMIC IMPLICATIONS

#### Environmental Benefits

- **Decreased carbon footprint**: The use of waste materials such as fly ash, GGBFS, and recycled aggregates minimizes the demand for virgin materials like cement and natural aggregates, which are typically associated with high carbon emissions in their extraction and manufacturing processes. By diverting wastes from landfills and industrial processes, green concrete has a potential for mitigating greenhouse gas emissions.

- **Conservation of natural resources**: The utilization of recycled materials in concrete production conserves natural resources that are normally used as aggregates in concrete—such as sand, gravel, and limestone—that are finite and often mined at significant environmental cost. This conservation helps to preserve natural ecosystems and reduces habitat destruction associated with resource extraction.

#### Economic Feasibility and Cost-Effectiveness

- **Material Cost Savings**: Green concrete can save money if expensive virgin materials are substituted with cheaper or even free waste materials. For example, fly ash and GGBFS can often be purchased at a lower unit cost than cement, ultimately reducing the overall production cost.

- **Construction Cost Savings**: When green concrete offers improved durability and reduced maintenance requirements over its lifetime, life cycle cost savings may be achieved for buildings and civil infrastructure works.

- **Market Demand and Regulatory Incentives**: As construction and environmental regulations put more emphasis on sustainability in the built environment, market demand will increase for green concrete. Companies that have the capacity for producing green concrete with competitive functionality will therefore have the opportunities of benefiting from market advantages and governmental incentives to apply green technologies in their work.

#### Life Cycle Assessment Studies and Sustainability Considerations

- **Holistic approach**: Life cycle assessment (LCA) studies provide environmental impacts from cradle to grave, which may include raw material extraction, manufacturing, transportation, use of concrete, and end-of-life disposal, among other factors. Such results would give a very good insight into the overall sustainability of green concrete in comparison with conventional alternatives.

- **Measuring sustainability indicators**: Concrete sustainability is more than the impact on the environment; it has social, economic, and cultural features. Measurement of green concrete against sustainability indicators is well appreciated for capturing concrete production performance and improvements that are necessary.

- **Continuous Improvement**: Research and development are aimed at improving environmental and economic performance in the field of green concrete by innovating with material technology, construction practices, and policy interventions. The development of green concrete will therefore undergo continuous improvement in terms of sustainability practices, thus ensuring that the material remains a viable solution to meet the needs of current and future generations while ensuring environmental integrity.
CHALLENGES AND FUTURE DIRECTIONS

Challenges and Limitations

Challenges and future directions of green concrete include ensuring the uniform quality of waste materials, removing regulatory bottlenecks, and handling public skepticism. Research needs to be geared towards maximizing the performance of waste materials, an understanding of long-term behavior, and full environmental and economic studies. The new technologies and the cooperation between the different stakeholders allow and promote innovation in green concrete. Adoption and implementation programs could benefit from education, policy assistance, industrial cooperation, and market opportunity. The construction industry can overcome these challenges and accelerate toward greener and more sustainable concrete solutions only by addressing these weaknesses and capitalizing on opportunities to advance.
Research Gaps and Opportunities for Advancement

Further research is required for the proper characterization of waste materials and for the optimization of their behavior in concrete mixes. This involves improved processing, blending strategies, and chemical treatments with a view to making them more effective in concrete manufacture. Furthermore, the research has to be carried out on long-term durability and performance of green concrete, without which it is difficult to sustain green concrete. Its resistance to different environmental conditions, including aggressive chemicals, freeze-thaw cycles, and mechanical loading, can be investigated to provide insight into its real application. Life cycle assessments and cost-benefit analysis should be conducted on green concrete materials, which can compare their environmental, economic, and social impact with conventional materials. In this way, conclusions can be drawn and policies could be set in favor of green concrete materials. Development of new technologies, such as 3D printing, nanotechnology, and advanced material science, opens the door for new innovations and applications of green concrete. Such innovations will open the way for sustainable construction practices that will help in a smooth transition toward the use of eco-friendly building materials.

CONCLUSION

In conclusion, using wastes in green concrete can be promising towards sustainable construction practices. In view of the aforesaid environmental concerns, natural resource conservation, and saving on the use of conventional materials, green concrete avails itself as a solution to some of the challenges brought about by urbanization and industrialization. Although some barriers and skepticism from the public have still been in existence, current and future research and technology developments are the means that can unlock these barriers, making green concrete a reality in construction. Collaborations across different sectors and investments in innovative solutions make the transition to greener and more sustainable concrete solutions a reality, ensuring a resilient and green-built environment for future generations.

REFERENCES


