International Research Journal of Education and Technology
Peer Reviewed Journal, **ISSN 2581-7795**

IMPLEMENTATION OF CIRCULAR ECONOMY PRINCIPLES IN CONSTRUCTION WASTE MANAGEMENT

Md Sameem Akhtar[a], Vinay Kumar Singh Chandrakar[b],

**M.Tech. Scholar[a], Associate Professor[b], Madhyanchal Professional University, Faculty of Engineering & Technology, School of Civil Engineering Bhopal, M.P., India

Abstract

The construction industry is one of the largest consumers of natural resources and a major contributor to environmental degradation due to the generation of vast amounts of construction and demolition waste. In line with sustainable development goals, this study explores the implementation of circular economy (CE) principles in construction waste management through the innovative reuse of biomedical waste ash and 100% recycled organic aggregate in concrete production. The primary objective is to reduce the reliance on natural raw materials while promoting waste valorization and environmental sustainability.

In this experimental study, cement is partially replaced with biomedical waste ash in varying proportions ranging from 0% to 14%, while natural coarse aggregate is completely substituted with 100% recycled organic aggregate derived from processed construction or agricultural waste. Biomedical waste, a growing environmental and public health concern in India, is thermally treated to produce ash with pozzolanic properties suitable for cement replacement. The concrete mixes are evaluated for key mechanical and durability parameters, including compressive strength, split tensile strength, water absorption, and sorptivity.

The results demonstrate that concrete incorporating biomedical waste ash and recycled organic aggregate can achieve comparable or even improved performance characteristics under optimal replacement levels. This approach not only diverts hazardous biomedical waste and organic matter from landfills and incineration but also reduces the carbon footprint associated with cement production and natural aggregate mining.

The findings support the feasibility of integrating circular economy strategies into construction materials, offering a sustainable and eco-friendly alternative to conventional practices. The study contributes to advancing resource-efficient construction technologies and highlights the importance of regulatory frameworks, stakeholder engagement, and innovative materials in promoting circularity in the built environment.

Key Words: - biomedical waste, natural aggregate, mechanical and durability parameters, compressive strength, split tensile strength

Introduction

The construction industry is one of the largest consumers of natural resources and a major contributor to global waste generation. Traditional linear models of "take-make-dispose" have led to significant environmental degradation, depletion of finite resources, and increased landfill burden. In response to these challenges, the circular economy (CE) has emerged as a sustainable alternative that emphasizes resource efficiency, waste minimization, and the continual use of materials.

The circular economy in construction aims to close the loop by designing out waste and pollution, keeping products and materials in use for as long as possible, and regenerating natural systems. By rethinking construction processes and materials management, CE principles can drastically reduce the environmental impact of building activities. This involves strategies such as material recovery, reuse of building components, recycling of construction and demolition (C&D) waste, and designing buildings for disassembly and adaptability. Construction Waste Management (CWM) under circular economy principles shifts the focus from mere disposal to preventive strategies, such as modular construction, prefabrication, digital planning (e.g., BIM), and efficient supply chain management. Implementation also requires collaboration among stakeholders, regulatory support, and investment in innovative technologies that support circular practices. This paradigm shift not only conserves resources and reduces emissions but also generates economic benefits through cost savings, job creation in recycling industries, and the development of new markets for secondary materials. Therefore, the integration of CE principles into construction waste management presents a transformative opportunity to align the construction industry with the goals of sustainability, resilience, and long-term economic viability. The construction industry is one of the largest consumers of natural resources and a major generator of solid waste globally. In the face of growing environmental challenges, the traditional linear model of "take-make-dispose" is proving to be unsustainable. This has prompted a shift towards Circular Economy (CE) principles, which aim to minimize waste, extend material life cycles, and promote resource efficiency through reuse, recycling, and recovery. The integration of CE in Construction Waste Management (CWM) not only addresses sustainability concerns but also enhances the economic viability of construction practices. Among the various waste streams, biomedical waste—which includes discarded materials from hospitals, clinics, and laboratories—has become a major environmental and health hazard due to its infectious and hazardous nature. With India generating over 550.9 tons of biomedical waste daily and the figure rising annually, safe and sustainable disposal methods are urgently needed. Recent studies have explored the feasibility of using biomedical waste ash (BMWA), generated by incinerating biomedical waste, as a partial replacement of cement in concrete. This approach not only diverts hazardous waste from landfills but also reduces the dependency on energy-intensive cement, thereby aligning with CE principles. Similarly, the use of Recycled Concrete Aggregates (RCA), obtained from demolition and construction debris, is gaining traction as a sustainable alternative to natural aggregates. RCA use helps to preserve natural resources, reduce landfill usage, and lower the carbon footprint of concrete production. By incorporating biomedical waste ash and recycled aggregates into concrete, the construction industry can create a closed-loop system where waste materials are repurposed as valuable inputs. This study explores the implementation of circular economy strategies in construction waste management by evaluating the performance, environmental benefits, and feasibility of concrete produced using BMWA and RCA. The successful integration of these materials can significantly contribute to sustainable construction, promote waste valorization, and support India's goal of achieving a low-carbon, resource-efficient economy.

Literature Review

B. Prasanth et al (2019) biomedical waste is generated from hospitals, health clinics, and laboratories. The disposal of this waste ash is an environmental concern, as it can potentially lead to the spread of infectious diseases. In India, biomedical waste generation currently amounts to approximately 550.9 tons per day, with an annual growth rate of 8%. There is a potential for utilizing biomedical waste ash (BMWA) in concrete production.

In this study, the compressive strength, split tensile strength, and durability of concrete were evaluated with partial replacement of Ordinary Portland Cement (OPC) by biomedical waste ash at varying proportions (5%, 10%, 15%, and 20%), while keeping met kaolin content constant at 20%. The mechanical properties were assessed by casting 30 concrete cubes and 25 cylinders. For durability assessment, the concrete cubes were subjected to chloride attack using sodium chloride (NaCl), and the results were compared with those of control concrete. Additionally, the flexural behavior of reinforced concrete beams made with the binder containing biomedical waste ash and met kaolin was investigated under different loading conditions. The performance of these beams was compared with that of beams made with conventional OPC.

Udit Kumar et al (2016) biomedical waste management is a growing concern, especially in developing countries like India. Biomedical waste refers to any waste generated during the diagnosis, treatment, or immunization of human beings or animals, or in research activities pertaining to these fields. This includes materials like used syringes, bandages, gloves, human tissues, discarded medicines, and other infectious materials. In India, with the rapid increase in population and healthcare facilities, the generation of biomedical waste has significantly risen. Currently, the country produces over 550.9 tons of biomedical waste daily, and this figure is increasing annually by about 8%. Improper disposal or management of this waste poses serious risks to public health and the environment. The hazardous components of biomedical waste can lead to the spread of infections, contamination of water sources, soil degradation, and air pollution. The key environmental issue associated with biomedical waste is its toxic, infectious, and non-biodegradable nature. When not treated and disposed of correctly, it can lead to the spread of life-threatening diseases, such as HIV, hepatitis, and bacterial infections. Traditional methods of disposal, like incineration, can lead to the release of dioxins, furans, and other harmful gases, which further worsen air quality and contribute to climate change. Due to these concerns, researchers and engineers are looking for sustainable and eco-friendly methods to manage and reuse biomedical waste. One such emerging solution is the conversion of biomedical waste into ash (through incineration or thermal treatment) and then utilizing this ash as a partial replacement for cement in concrete. The study concludes that biomedical waste ash can be safely and effectively used as a partial replacement for cement in concrete production. This not only helps in managing hazardous waste but also contributes to the reduction of cement usage, thereby offering economic and environmental benefits. However, it is important to ensure that the ash used is non-toxic and properly treated before being added to concrete. More long-term studies and field applications are recommended to establish its widespread use in the construction industry.

Methodology

The methodology for implementing circular economy principles in construction waste management involves a systematic approach that prioritizes waste reduction, reuse, and recycling throughout the construction lifecycle. This begins with a thorough waste audit and material flow analysis at the design stage to identify opportunities for minimizing waste generation. Sustainable design strategies, such as modular construction and prefabrication, are integrated to reduce material use. The research methodology adopted for this study involves both qualitative and quantitative approaches to assess the feasibility and effectiveness of implementing Circular Economy (CE) principles in construction waste management (CWM)

Bio Medical Waste

Biomedical waste, also known as hospital or medical waste, refers to any waste containing infectious or potentially infectious materials generated during the diagnosis, treatment, or immunization of humans or animals, as well as during medical research. This waste includes solid or liquid items such as used bandages, discarded blood, surgical gloves, microbiological cultures, human or animal tissues, and sharps like needles and scalpels, whether used or unused. It may also encompass materials that appear to be from medical settings, such as packaging and infusion kits. Biomedical waste is distinct from general, chemical, radioactive, or industrial waste due to its potential to spread infections and cause injury, and thus requires special handling and disposal. It is commonly produced by hospitals, clinics, laboratories, dental and veterinary offices, and even home healthcare settings. Disposal of biomedical waste is a critical environmental and public health issue due to the potentially infectious and hazardous nature of the materials involved. Biomedical waste, often generated in hospitals, clinics, laboratories, and even in homes where medical treatment is administered, includes items such as used syringes, bandages, surgical instruments, pathological waste, and other materials that have come into contact with bodily fluids. If not properly handled and disposed of, this waste can be a serious source of contamination and disease transmission.

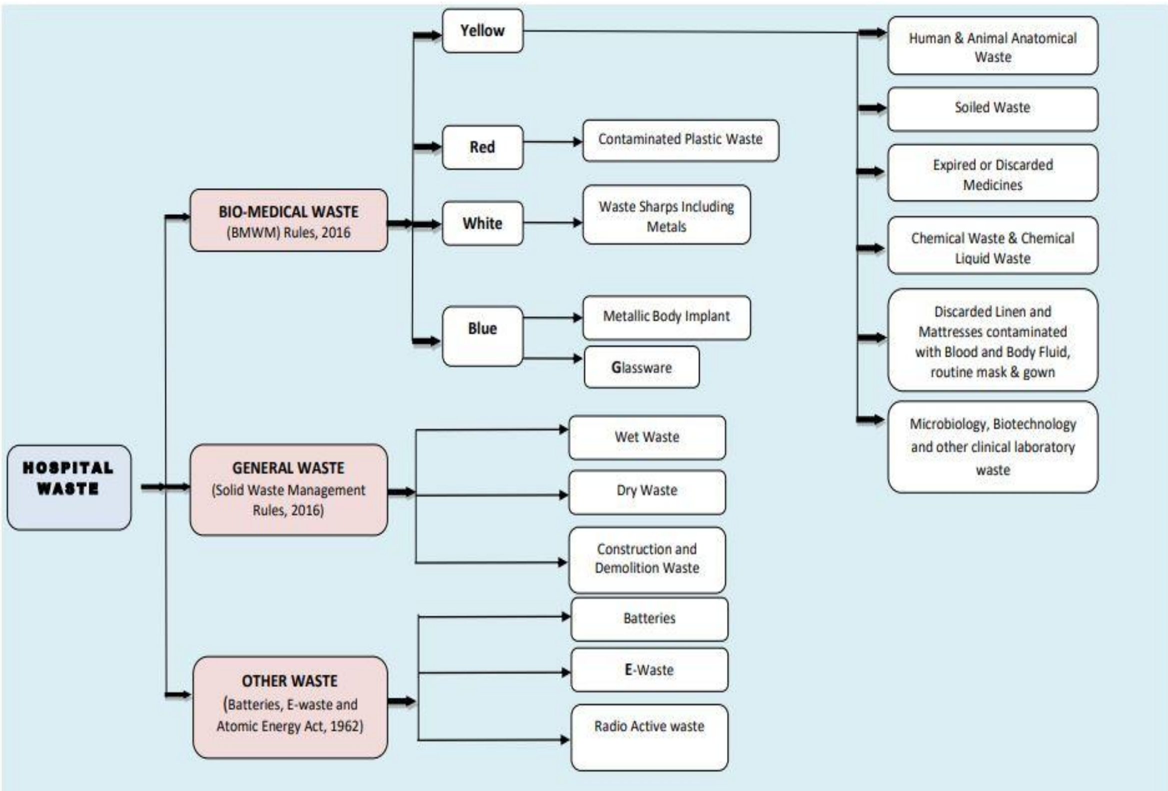

Figure 1 Hospital waste flow chart

Environmental and Human Health Concerns

A major concern is that biomedical waste is often infectious, meaning it may contain pathogens like bacteria, viruses, or fungi that can cause disease in humans or animals. When improperly disposed of—especially in open dumps, landfills, or through open burning—these pathogens can spread into the surrounding environment, contaminating soil, air, and water sources. This can lead to long-term environmental degradation and public health risks, including outbreaks of infectious diseases.

People living near landfills where biomedical waste is dumped may be routinely exposed to harmful substances or microbes. These substances can enter the body through inhalation, ingestion, or skin contact, especially if protective barriers like gloves or masks are not used. Long-term exposure can lead to bioaccumulation of toxic substances (e.g., heavy metals, persistent organic pollutants), which can disrupt the endocrine system, damage organs, or lead to cancer or other chronic health issues.

Result and Discussion

To assess the long-term performance and sustainability of concrete incorporating biomedical waste ash and 100% recycled aggregates, a series of durability tests were conducted in accordance with relevant IS and ASTM standards. These tests are crucial for evaluating the resistance of the modified concrete mix to environmental stressors and confirming its structural integrity over time.

Durability Test (Acid Attack)

The Acid Attack Durability Test is essential for validating the performance of waste-based concrete within a circular economy framework. It ensures that recycled materials not only reduce environmental impact but also meet durability requirements, paving the way for resilient and sustainable infrastructure solutions. In the implementation of circular economy principles in construction waste management, the Acid Attack Durability Test plays a vital role in assessing the long-term performance of concrete incorporating recycled materials such as hospital waste ash, recycled aggregates, or industrial by-products. This helps determine the suitability and sustainability of such materials in real-world applications, aligning with circular economy goals of reducing virgin material use and minimizing environmental impact. After curing, the specimens are immersed in a 5% solution of sulfuric acid (H_2SO_4) or hydrochloric acid (HCl) for a specific period, typically 28days.

Table 1 Weight reduction

Level of replacement (%)	Normal Weight in Kg	Reduced Weight in kg	% of Weight Reduction
0	8.15	7.80	4.29
1.75	8.20	7.85	4.27
3.5	8.15	7.80	4.29
5.25	8.25	7.90	4.24
7	8.20	7.95	3.05
8.75	8.15	7.95	2.45
10.5	8.35	8.20	1.80
12.25	8.30	7.90	4.82
14	8.35	7.85	5.99

This table shows that replacing conventional concrete ingredients with lighter materials (up to 14%) generally reduces the weight of concrete cubes, supporting the use of sustainable or recycled materials for producing lightweight concrete. However, the variation in weight reduction at different levels highlights the importance of consistent mix design and quality control. The maximum weight reduction of 5.99% occurs at 14% replacement, showing potential for efficient use in applications requiring lower dead load.

Conclusion

The results suggest that partial replacement of cement with the studied material leads to measurable weight reduction in concrete. The optimum range appears around 12.25% to 14%**,** where the weight reduction is maximized (up to 5.99%). However, due to fluctuations in the trend, it's recommended to further investigate the material properties**,** mixing behavior**,** and compatibility at each level of replacement. This will help determine the most efficient and consistent replacement percentage for practical applications in lightweight concrete production.

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