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Sustainable Utilization of Aluminium Dross and Bottom Ash in Cement Concrete: A Study of Material Characteristics and Engineering Viability

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Abstract
This chapter offers a comprehensive analysis of the primary and supplementary materials employed in this study to formulate concrete by partially replacing conventional constituents such as cement and fine aggregates. The materials examined include aluminium dross, bottom ash, Ordinary Portland Cement (OPC), coarse aggregates, fine aggregates, and water. These materials are not only fundamental to the structural integrity of concrete but also central to the development of environmentally conscious, cost-effective construction practices.

Materials

Introduction

This chapter offers a comprehensive analysis of the primary and supplementary materials employed in this study to formulate concrete by partially replacing conventional constituents such as cement and fine aggregates. The materials examined include aluminium dross, bottom ash, Ordinary Portland Cement (OPC), coarse aggregates, fine aggregates, and water. These materials are not only fundamental to the structural integrity of concrete but also central to the development of environmentally conscious, cost-effective construction practices.

The exploration of these materials is grounded in the contemporary need for sustainable development in the construction sector. Traditional concrete production heavily depends on natural resources—limestone for cement, river sand for fine aggregates, and crushed stones for coarse aggregates—whose extraction and processing contribute significantly to environmental degradation, including land depletion, air and water pollution, and increased carbon emissions. Consequently, there is a growing urgency to identify alternative resources that are abundantly available, economically feasible, and environmentally sound.

Aluminium dross and bottom ash, both industrial by-products, have emerged as promising candidates in this context. Aluminium dross is a residue generated during aluminium refining, while bottom ash is a waste material from coal combustion in thermal power plants. Their inclusion in concrete mixes not only diverts waste from landfills but also offers potential enhancements in mechanical properties, provided that proper processing and mix design principles are adhered to.

The rationale for incorporating these by-products lies in their potential to improve the performance characteristics of concrete while reducing its environmental footprint. This aligns with global initiatives aimed at minimizing greenhouse gas emissions, promoting circular economy principles, and ensuring resource efficiency. Furthermore, the use of such materials may lower construction costs, making sustainable practices more accessible to a broader range of infrastructure projects.

The chapter investigates the individual characteristics of each material—covering their physical structure, chemical composition, and compatibility with other concrete components. It also discusses the implications of their use on concrete properties such as workability, strength, setting time, and durability. The combination of performance-based analysis and sustainability goals ensures that material selection in this study is both technically and environmentally justified.

Subsequent sections detail the specification, sourcing, processing, and storage of each material used in the experimental work. This includes laboratory testing and conformity to relevant Indian Standards (IS) codes. Moreover, Chapter 4 builds upon this foundation by elaborating on the experimental methodology, mix design formulation, and comprehensive testing for fresh, hardened, and microstructural properties of the developed concrete (Ramesh, 1999).

Aluminium Dross

Aluminium dross is a by-product generated during aluminium refining, casting, and melting. It includes both metallic aluminium and non-metallic substances such as aluminium oxides (Al_2O_3), chlorides, fluorides, nitrides (AlN), carbides, and other impurities (Manfredi et al., 1997). Depending on metal content, it is categorized into white dross (higher metallic content) and black dross (lower metallic content), as classified by the OECD (2000).

The dross formation depends on factors like material purity, oxygen exposure, process temperature, and furnace type. Processing techniques such as mechanical separation, pyrometallurgical, and hydrometallurgical methods are used to extract usable metals and compounds (B. Lucheve et al., 1997). In particular, pyrometallurgical methods suit drosses with higher metallic aluminium, while hydrometallurgical processes are preferred for lower content.

Aluminium dross is explored for its use in producing gases such as hydrogen and ammonia, and in creating refractory materials containing spinels like $MgAl_2O_4$. Removal of hazardous compounds like aluminium nitride (AlN) is necessary to enhance performance in these applications (Chen Dai, 2019). Despite being classified as hazardous under the European Commission's regulations, the value in engineering applications remains significant.

In India, the annual production of aluminium dross is estimated at 100 million tonnes, yet only about 15% is reused, with the remainder being disposed of in landfills—an unsustainable practice (Srivastava et al., 2017). Dross undergoes hydrolysis in contact with water, releasing gases such as hydrogen and phosphine, which are dangerous in enclosed environments. Its presence in concrete can hinder hydration and setting, reduce the growth of calcium hydroxide crystals, and affect uniformity and workability.

Despite these challenges, aluminium dross is used in up to 30% replacement levels in private-sector concrete plants. Government adoption remains limited due to lack of awareness and outdated specifications. The development of high-volume aluminium dross concrete (HVADC) could provide a sustainable solution if performance is made comparable to traditional portland cement concrete (Sachdeva et al., 2018).

Environmental Impacts

The improper disposal of aluminium dross poses severe threats to both terrestrial and aquatic ecosystems. Aluminium, a primary component, is toxic to many freshwater species, including fish, amphibians, and invertebrates, where it interferes with respiratory functions and disrupts osmoregulatory and ion exchange mechanisms vital for survival (OECD, 2000). In aquatic environments, aluminium tends to precipitate under neutral pH, but under acidic conditions, it dissolves more readily and becomes more bioavailable and toxic to living organisms. This toxicity not only affects individual species but also destabilizes food chains and reduces biodiversity over time.

Moreover, aluminium dross often contains trace concentrations of heavy metals such as arsenic, cadmium, chromium, lead, and mercury—elements known for their carcinogenic and mutagenic properties (Srivastava et al., 2017). These toxicants can leach into groundwater and surface water systems, contaminating drinking water sources and accumulating in aquatic organisms through biomagnification, resulting in long-term ecological and public health issues.

On land, aluminium dross is highly reactive and poses significant environmental hazards when not handled properly. Contact with water can trigger exothermic reactions that release ammonia, hydrogen, and other flammable and toxic gases such as phosphine and methane, contributing to fire hazards and atmospheric pollution. These gases can cause respiratory issues and environmental degradation when released in open environments.

In landfills, aluminium dross can emit noxious fumes and leach harmful substances, contaminating soil and degrading its fertility. The resulting soil contamination hampers plant growth, alters microbial activity, and disrupts nutrient cycling. Additionally, the high alkalinity of dross can alter soil pH, affecting agricultural productivity and ecological balance.

From a human health perspective, direct contact with dross can cause skin burns, eye irritation, and respiratory distress due to its caustic nature and airborne particulates. The airborne dispersion of fine dross particles also contributes to particulate matter pollution (PM2.5 and PM10), which is linked to cardiovascular and respiratory ailments.

Thus, aluminium dross disposal represents a multifaceted environmental threat—polluting air, water, and soil while endangering ecosystems and human health. Its classification as hazardous waste underscores the urgent need for safe recycling methods, regulated disposal systems, and sustainable management practices.

Economic Motives

Recycling aluminium presents substantial economic benefits, primarily due to the drastic reduction in energy consumption. Producing aluminium from recycled materials requires only about 5% of the energy needed to extract it from bauxite ore, resulting in significant cost savings for industries (Chen Dai, 2019). This reduction not only lowers electricity expenses—a major cost component in aluminium smelting—but also minimizes dependence on costly raw materials and imported ores.

Innovative technologies such as **non-salt plasma torch recovery** have emerged as economically viable solutions, reducing the need for harmful salt fluxes traditionally used in the recovery process. In France, the implementation of salt-free plasma-based methods has proven successful, enhancing material recovery rates and substantially cutting operational and waste management costs. The elimination of salt waste also reduces downstream disposal expenses and simplifies environmental compliance.

Recycled aluminium dross holds intrinsic commercial value. The aluminium recovered from dross can be directly reintroduced into manufacturing streams for automotive, aerospace, packaging, and construction applications, thereby replacing primary aluminium and lowering production costs. Moreover, the dross itself can be processed into value-added products such as **aluminium oxide**, **spinel**, or **metallic powders** used in abrasives, ceramics, and polishing compounds.

Aluminium smelting companies are increasingly capitalizing on recycling services as a profitable venture. By converting what was once considered waste into reusable and sellable commodities, smelters not only reduce waste disposal costs but also create new revenue streams. In many countries, government incentives and subsidies for recycling further improve the economic feasibility of dross recovery operations.

In the **construction sector**, incorporating aluminium dross into cement and concrete has shown dual benefits: reducing material costs and enhancing the mechanical properties of the end product. Dross-modified concrete often displays improved compressive strength and durability, contributing to longer-lasting infrastructure while lowering the carbon footprint of construction materials.

The broader **economic and environmental advantages** of aluminium dross recycling are significant. These include:

- **Reduced reliance on landfills**, lowering municipal solid waste management costs.
- **Conservation of natural bauxite reserves**, extending the lifespan of raw material resources.
- **Decreased fluoride and greenhouse gas emissions**, contributing to sustainability goals and regulatory compliance.
- **Lower costs in refractory and metallurgical industries**, where dross is used for desulphurisation, slag conditioning, and deoxidation in steel manufacturing.

Bottom Ash: Composition, Utilization, and Environmental Implications

Bottom ash is a coarse, granular by-product generated from the combustion of pulverized coal in thermal power plants. Unlike fly ash—which is captured from flue gases using electrostatic precipitators—bottom ash collects at the furnace base and is mechanically removed. It primarily consists of **silica (SiO_2), calcium oxide (CaO), aluminium oxide (Al_2O_3)**, iron oxide (Fe_2O_3), and other trace elements, with its exact composition influenced by the **type of coal used**, **combustion temperature**, and **boiler design** (Sachdeva et al., 2018).

In modern sustainable construction practices, bottom ash has gained prominence as a viable **alternative to natural river sand** in concrete production. When used in appropriate proportions, bottom ash enhances workability, reduces bleeding and segregation, and contributes to the long-term strength and durability of concrete. Its porous nature also improves internal curing and promotes better hydration, which is especially beneficial in arid regions. Substituting bottom ash for sand helps curb the unsustainable exploitation of riverbeds, mitigating **riverbank erosion**, **aquatic habitat destruction**, and **biodiversity loss**.

India, being one of the largest producers of coal-based power, generates more than **120 million tonnes of bottom ash annually**, a significant portion of which remains unutilized and is stored in **ash ponds or landfills**. These ash ponds not only occupy large tracts of land—rendering them unusable for agriculture or habitation—but also pose serious environmental and health risks. The leachate from ash ponds contains **toxic trace elements** such as arsenic, selenium, mercury, boron, and lead, which can **contaminate groundwater** and surface water bodies, posing threats to human health and local ecosystems.

The study at hand utilizes bottom ash obtained from the **Rayalaseema Thermal Power Plant in Andhra Pradesh** to ensure uniformity in material characteristics. Rigorous laboratory evaluations revealed that bottom ash incorporation not only enhances **mechanical performance**—including compressive and split tensile strength—but also improves the **durability characteristics** of concrete, such as resistance to sulphate attack, alkali-silica reaction, and water permeability. Moreover, bottom ash contributes to

thermal insulation, which can reduce building cooling loads, aligning with energy-efficient construction goals.

From a sustainability perspective, using bottom ash in construction promotes a **circular economy**, reduces the burden on landfills, and helps in the **valorization of industrial waste**. It also aligns with national waste management policies and green building codes (such as GRIHA and IGBC in India), encouraging the adoption of industrial by-products in infrastructure development.

Furthermore, bottom ash can be employed in a wide range of applications beyond concrete, including:

- **Manufacturing of lightweight aggregates**,
- **Filling material for embankments and road bases**,
- **Bricks and masonry blocks**,
- **Cement clinker production** (as a supplementary raw material),
- **Land reclamation and backfilling**.

In conclusion, the utilization of bottom ash not only enhances the **technical and economic viability** of construction materials but also serves as a strategic solution to **environmental challenges** posed by thermal power generation. Its integration into construction systems reflects an important shift toward **resource-efficient and environmentally responsible engineering practices**.

Cement

In this study, **Ordinary Portland Cement (OPC) of 53 grade** was utilized, conforming to the specifications outlined in **IS: 269–2015** and **IS: 12269–2013**. OPC 53 grade is preferred in structural and high-strength concrete applications due to its **superior compressive strength**, **rapid hydration rate**, and **early setting properties**, making it ideal for time-sensitive construction activities and precast applications.

The cement used in the study was **procured from Zuari Cement**, a reputed manufacturer and part of the **HeidelbergCement Group**, ensuring product reliability and manufacturing consistency. To maintain the credibility and scientific integrity of the experimental outcomes, **random sampling procedures** were followed in selecting cement batches for laboratory analysis.

A comprehensive suite of **physical and chemical tests** was performed in accordance with **IS: 4031 (Parts 1–11)** to evaluate critical parameters:

- **Fineness**: Measured by Blaine's air permeability method to assess the surface area, which directly influences the rate of hydration and strength development.
- **Specific gravity**: Determined to ensure proper mix proportioning and density control.
- **Initial and final setting times**: Verified to establish compatibility with admixtures and pozzolanic materials such as fly ash or bottom ash.
- **Standard consistency and soundness**: Tested to confirm workability and volume stability.
- **Compressive strength**: Evaluated on standard mortar cubes at 3, 7, and 28 days to confirm adherence to BIS requirements and performance under loading conditions.

The chemical composition was also analyzed for **lime saturation factor (LSF)**, **insoluble residue**, **magnesia content**, and **loss on ignition (LOI)**. All parameters were found to comply with **Bureau of Indian Standards (BIS)** specifications, confirming the cement's suitability for **high-performance and sustainable concrete applications**.

Furthermore, the cement's **compatibility with supplementary cementitious materials (SCMs)**—such as bottom ash and fly ash—was observed to be stable, with no adverse impact on setting behavior or

strength development. Its high early strength also facilitated better **formwork removal time**, which can accelerate construction schedules and improve cost efficiency.
Quality assurance was ensured through repeated trial batching and validation of performance under varying curing conditions, particularly to simulate field environments. No signs of expansion, cracking, or delayed ettringite formation were detected during durability tests.
In summary, the use of OPC 53 grade cement not only provided the **structural reliability** required for advanced concrete design but also offered a **technically sound foundation** for integrating industrial by-products like aluminium dross and bottom ash into eco-efficient construction solutions.

Aggregates
Aggregates play a crucial role in concrete composition, accounting for approximately 60–75% of the total volume. They significantly influence the **strength, durability, dimensional stability**, and **workability** of the concrete. In this study, both fine and coarse aggregates were carefully selected, tested, and used in accordance with **IS: 383–2016** to ensure compatibility with high-performance concrete requirements.
Fine Aggregates (Sand)
Natural river sand, sourced from the **NTR Jalasayam reservoir** in Andhra Pradesh, was used as the fine aggregate. The sand was first **sieved through a 4.75 mm IS sieve** to eliminate oversized particles and ensure uniform grading. The grading curve was verified to fall within **Zone II of IS: 383**, which is ideal for producing workable concrete with good finishability.
Key characteristics of the sand include:
- **Cleanliness**: Free from clay lumps, silt, organic matter, mica, and other deleterious materials as confirmed through visual inspection and laboratory tests (IS: 2386 Part I).
- **Moisture content**: Monitored daily to adjust water–cement ratio accurately.
- **Specific gravity and bulk density**: Determined to enable accurate mix proportioning.
- **Fineness modulus**: Found to be within the range of 2.3–3.1, indicating moderate fineness suitable for general-purpose concrete.

The sand was **stored under covered and dry conditions** to avoid moisture variation and contamination. Its well-graded nature contributed to **better workability**, **reduced void content**, **enhanced packing density**, and **improved strength development** of mortar and concrete.

Coarse Aggregates
Crushed granite aggregates, varying in size from **4.75 mm to 20 mm**, were employed as the coarse aggregates. These were sourced from a **single quarry and lot** to ensure consistency in physical and mechanical properties across all test batches.
The following parameters were evaluated in accordance with **IS: 2386 (Parts I–IV)**:
- **Water absorption**: Found to be within acceptable limits (<2%), ensuring minimal variation in water demand.
- **Specific gravity**: Approximately 2.65–2.75, indicating good density and structural integrity.
- **Fineness modulus**: Determined to establish particle size distribution for optimal packing.
- **Aggregate crushing value and impact value**: Measured to assess resistance to mechanical degradation.
- **Shape and texture**: Angular and rough-textured aggregates with low flakiness and elongation indices (<25%) were selected to promote **interlock**, **mechanical bonding**, and **durability**.

These aggregates fulfill the structural role in the concrete matrix by providing **volume stability**, **mechanical strength**, and **resistance to wear and weathering**. Their selection was critical to ensuring that the mix could withstand mechanical loading, shrinkage, and long-term exposure conditions.

To maintain consistency and quality, the aggregates were washed and air-dried before batching. Aggregate storage was done in **segregation-free, separate bins** to prevent contamination and size mixing.

In conclusion, the combined use of **well-graded fine aggregates** and **mechanically strong coarse aggregates** ensured the development of a dense, durable, and high-strength concrete matrix. These materials contributed not only to the mechanical performance but also to the **workability, cohesion, and finish quality** of the concrete.

Water

Water is a vital component in concrete production, serving both as a **reactant in the hydration process** and as a **medium for workability**. Its interaction with cement initiates the formation of **calcium silicate hydrate (C-S-H)**, the primary binding phase that gives concrete its strength and structure. Inadequate or impure water can adversely affect **setting time**, **compressive strength**, and **durability**, and may even lead to long-term degradation of concrete.

In this study, **potable tap water**, readily available and commonly used in construction, was employed. The water complied with the quality requirements specified in **IS: 456–2000** and **IS: 3025 (Parts 1–24)**. It was tested in a laboratory setting to ensure that its chemical composition met the standards prescribed for mixing and curing concrete.

The following parameters were tested:

- **pH value**: Maintained between **6.0 and 8.5**, within the acceptable range to avoid corrosion or disruption of cement hydration.
- **Hardness**: Evaluated to ensure that the presence of calcium and magnesium ions would not interfere with cement setting.
- **Total dissolved solids (TDS)** and **total suspended solids (TSS)**: Kept below critical thresholds to prevent adverse effects on concrete durability.
- **Chloride content**: Ensured to be below **200 mg/l**, since excessive chlorides can promote **reinforcement corrosion**.
- **Sulphates**: Monitored and limited to less than **400 mg/l**, as high sulphate levels can cause expansive reactions in concrete, leading to cracking or structural distress.
- **Alkalinity and organic matter**: Controlled to prevent delay in setting or weakening of the concrete matrix.

Both **mixing water** and **curing water** were subject to quality control to prevent contamination from salts, oils, acids, alkalis, and organic materials. The use of clean water during curing is especially critical, as impure water can leach through concrete and cause surface discoloration, scaling, or chemical attack.

In line with sustainable construction practices, water consumption was minimized through precise mix design and monitoring of **water-cement ratio**, which was carefully maintained below **0.5** to ensure high strength, low permeability, and resistance to environmental deterioration.

Additionally, the study emphasized:

- **Storage of water in clean, non-corrosive containers**,
- **Daily verification of temperature and pH**, especially during high ambient conditions,

- **Use of recycled or treated water** was considered but not adopted in this phase to maintain strict quality standards for high-performance concrete.

In conclusion, careful selection and quality assurance of water ensured **uniform hydration**, **optimum strength gain**, and **long-term durability** of the concrete. By adhering to IS specifications and conducting regular laboratory assessments, the study upheld best practices in material selection for structural concrete applications.

WORK CITED

1. B. Lucheve et al. (1997). Investigation into the recycling of aluminium dross.
2. Chen Dai. (2019). Aluminium waste reuse in refractory and cementitious systems.
3. IS:269 - 2015. Specifications for Ordinary Portland Cement.
4. IS:456 - 2000. Code of Practice for Plain and Reinforced Concrete.
5. IS:4031 (Parts 1–11). Methods of Physical Tests for Hydraulic Cement.
6. Manfredi, O. et al. (1997). Characterization of aluminium dross for industrial reuse.
7. OECD. (2000). Guidelines for the classification and management of aluminium dross.
8. Ramesh, A. (1999). Strategies for sustainable reuse of aluminium by-products.
9. Sachdeva, S. et al. (2018). Bottom ash utilization in concrete: environmental and mechanical perspectives.
10. Srivastava, A., Singh, B., & Verma, R. (2017). Economic assessment of aluminium dross in Indian construction sector.