# UTILISATION OF ALUMINIUM DROSS AS A PARTIAL REPLACEMENT OF CEMENT IN GREEN CONCRETE: A DETAILED REVIEW

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## ABSTRACT
Concrete, composed of cement, aggregates, and water, remains fundamental to construction worldwide. However, cement production significantly contributes to global $CO_2$ emissions due to energy-intensive manufacturing processes. Growing environmental concerns have prompted researchers to explore sustainable alternatives that reduce concrete's environmental impact while maintaining structural performance. The construction industry faces increasing pressure to adopt circular economy principles and minimise its environmental footprint through innovative waste utilisation strategies. This review examines aluminium dross, a hazardous waste byproduct from aluminium smelting, as a partial cement replacement in sustainable concrete formulations. Typically requiring costly disposal methods, aluminium dross offers unique opportunities for eco-friendly construction practices. Studies demonstrate that this industrial waste possesses pozzolanic properties and filler capabilities, potentially improving concrete's mechanical strength and durability. The chemical composition of aluminium dross contains alumina and silica compounds that contribute to its cementitious behaviour. Research indicates that optimal replacement levels can maintain or even enhance concrete performance while addressing waste management concerns.

Incorporating aluminium dross provides dual benefits by reducing cement consumption and associated carbon emissions while converting problematic waste into valuable construction material. This approach addresses both environmental sustainability and waste management challenges, making aluminium dross a promising material for green concrete technologies. Furthermore, the utilisation of aluminium dross can enhance the economic viability of concrete production by reducing raw material costs.

**Keywords**: Aluminium Dross, Green Concrete, Sustainable Construction, Partial Cement Replacement, Industrial Waste Utilisation, Workability, Compressive Strength, Flexural Strength.

## I. Introduction
The rapid growth of the global population has led to a corresponding surge in waste generation across various sectors, including industrial manufacturing, commercial enterprises, and residential communities. These waste materials are broadly classified into two primary categories: biodegradable and non-biodegradable substances. Non-biodegradable wastes pose particularly severe environmental challenges as they persist in the ecosystem for extended periods without natural decomposition, creating long-term pollution concerns and waste management crises. Among the various industrial waste streams, aluminium dross represents a significant non-biodegradable byproduct generated during aluminium smelting and refining processes. This hazardous waste material typically accumulates in industrial stockpiles or requires expensive disposal in specialised landfills, contributing to environmental degradation and economic burden for aluminium producers. The

aluminium industry generates millions of tonnes of dross annually worldwide, making its sustainable management a critical environmental priority.
The construction industry, being one of the largest consumers of natural resources, offers promising opportunities for waste material utilisation through innovative material development. Concrete, as the second most consumed substance globally after water, relies heavily on cement production, which accounts for approximately 8% of global carbon emissions. This environmental impact, combined with the depletion of natural aggregates and the need for sustainable construction practices, has driven researchers to explore alternative materials that can partially replace conventional cement. Recent investigations have revealed that aluminium dross possesses pozzolanic properties due to its alumina and silica content, making it suitable for incorporation into concrete mixtures. The utilisation of aluminium dross as a partial cement replacement presents a dual solution: reducing industrial waste accumulation while developing environmentally friendly concrete formulations. This approach aligns with the principles of a circular economy by transforming waste materials into valuable construction resources, thereby addressing both waste management challenges and sustainable building material development. This study focuses on evaluating the feasibility and performance characteristics of green concrete incorporating aluminium dross as a partial cement replacement, contributing to waste reduction strategies and sustainable construction practices while maintaining structural integrity and durability requirements.

## II. Literature

The extent of research that has been undertaken on this topic thus far is relatively constrained. This section gives an outline of the key findings from previous studies, encapsulating their importance in the field.
Budda Damodhara Reddy et al. [2024] Concrete produced from cement, natural sand, aggregate, and water represents a fundamental building material globally. Excessive dependence on natural resources causes environmental damage, material shortages, pollution, and elevated carbon emissions, creating significant ecological impacts. Using aluminium dross and bottom ash in controlled quantities provides economic advantages by enabling sustainable project development through cost-effective, environmentally responsible advanced materials. This research examines the practical use of aluminium dross and bottom ash as sustainable construction components. Results show satisfactory strength and durability characteristics in concrete formulations. Microstructural analysis using thermogravimetric analysis (TGA) and Fourier transform infrared spectroscopy (FTIR) confirms that adding aluminium dross and bottom ash to concrete improves environmental sustainability.
Sancheng Qing et al. [2024] Toxic contaminants in phosphogypsum (PG) and aluminium dross (AD) limit their widespread use in engineering applications. This research examined using AD and PG as cement supplements to minimise environmental impact and reduce landfill requirements. Various characterisation techniques analysed AD behaviour at different heating temperatures. Testing evaluated compressive strength, soluble phosphorus/fluorine levels, hydration heat, and expansion in samples containing AD, PG, and Portland cement (PC). Findings revealed that 900°C-treated AD enhanced nitrogen removal while preserving hydration properties. Heat treatment at 900°C improved gypsum and calcium silicate dissolution, promoting ettringite (AFt), calcium silicate hydrates (C-S-H), and calcium aluminate hydrates (C-A-H) formation. The optimal blend of 14% heated aluminium dross (HAD), 6% PG, and 80% PC produced maximum compressive strength of 25.87 MPa. This work presents an innovative method for utilising both PG and AD together, promoting sustainable cement production from industrial waste materials.
Muñoz-Vélez, M.F. et al. [2023] This study examined the feasibility of creating an industrial plant to process aluminium dross into cement-compatible raw materials. Technical analysis evaluated washing and grinding operations. X-ray diffraction analysis showed 88% AlN reduction (a compound producing ammonia when wet) after washing treatment. Impact milling provided optimal grinding

performance. Economic analysis using cash flow models indicated that a USD 0.12/kg minimum selling price would generate 9.7% returns over five years. Results offer opportunities for metallurgical and construction industries to produce low-carbon products using recycled aluminium dross. The research also supports regulators and policymakers in creating frameworks and incentives to promote corporate investment in sustainable practices.

Aadil Hameed [2023] This investigation replaced cement with varying proportions of Aluminium waste powder (AWP), ranging from 2.5% to 10%, to develop practical mortar mixtures. Specimens measuring 50 mm were cured for 3, 7, and 28 days to evaluate flowability, density, and compressive strength characteristics. A constant water-cement ratio of 0.50 was maintained across all mix compositions. Results demonstrated that increasing AWP content reduced mortar flowability. Water-cured specimens showed decreased density and compressive strength with higher AWP percentages. Compressive strength analysis revealed that up to 2.5% AWP addition maintained acceptable strength values, while 10% addition caused significant strength reduction. The 2.5% AWP replacement achieved the highest compressive strength among all tested percentages at 28 days of curing.

Arpitha D J and Dr. Kannam Praveen [2022] Using alternative materials in concrete manufacturing has gained popularity, offering improved concrete characteristics and economic benefits. This study reports experimental results on employing aluminium dross (AD) and ground granulated blast furnace slag (GGBS) as partial cement substitutes in M35 grade concrete. Cement substitution involved systematic testing with constant 5% aluminium dross and variable GGBS proportions of 0%, 10%, 20%, 30%, and 40% to determine optimal replacement ratios. Through these trials, the best percentage combinations were established for superior concrete performance. Findings showed that combining 5% aluminium dross with 30% GGBS substitution produced the highest concrete strength across all tested mixtures.

Yujie Xue et al. [2022] Aluminium dross (AD) represents hazardous waste containing valuable metallic aluminium and reactive aluminium nitride (AlN). The intimate association of Al and AlN complicates separation processes. This research developed a mechanical milling technique using steel bars and balls as grinding media. Milling reduced AD particle size across ranges: 0.425–2 mm, 0.15–0.425 mm, 0.08–0.15 mm, and below 0.08 mm. Approximately 90% of particles fell within the 0.08–2 mm fraction after ball milling. Metallic Al concentrated in particles exceeding 0.425 mm (48.5%), while AlN predominated in the 0.15–0.425 mm fraction (64.9%). Optimised milling conditions achieved 65% Al recovery and 90% AlN separation efficiency, offering effective pretreatment for industrial AD recovery and AlN removal.

Abdul Qader Nihad Noori et al. [2021] This study investigated the mechanical properties of cement mortar incorporating aluminium scrap at varying percentages (1%, 2%, 3%, 4%, and 5%) as sand replacement by weight with Ordinary Portland Cement (OPC). Results demonstrated that aluminium waste can be utilised within specific limits, though compressive strength decreased with higher Als percentages. A notable finding was the volume expansion of mixtures with increased Als content. The findings suggest potential applications for this mortar type in lightweight construction elements, including slabs and bricks. A general formula was developed through regression analysis and experimental data to predict mortar compressive strength based on specimen age and aluminium replacement quantity.

Mohamed Hamdy Elseknidy et al. [2020] This study evaluated cement replacement with aluminium dross and fly ash, plus sand substitution using quarry dust. Nine mixtures were tested with aluminium dross ranging from 5 to 20% of cement weight. Optimal aluminium dross content was established at 15% fly ash, then quarry dust was added at 10-40% of natural sand. Mechanical and durability properties were assessed for selected compositions. Results showed that 15% fly ash, 10% aluminium dross, and 20% quarry dust achieved superior performance compared to conventional concrete. Using industrial waste reduces costs and environmental impact while maintaining structural integrity.

Amar Gote et al. [2019] This research investigates aluminium dross utilisation as a cement replacement in concrete applications. Since aluminium is extensively used in construction and generates substantial waste during production, incorporating aluminium dross reduces raw material consumption compared to conventional concrete. The study demonstrates that aluminium dross can enhance concrete corrosion resistance within specific limits. Cement was replaced with aluminium dross at 5%, 10%, and 15% by weight. Concrete cubes were cast and tested for compressive strength at 7, 15, and 28 days of curing periods.

Panditharadhya B J et al. [2018] This research examines secondary aluminium dross as a partial cement substitute in concrete production. Testing at replacement levels of 5%, 10%, 15%, and 20% by weight revealed that 15% replacement delivers optimal performance. The modified cement paste exhibited extended initial setting times and reduced final setting times, making it advantageous for hot climate construction. Evaluation of M40 grade concrete specimens showed that mechanical properties, including compressive strength, split tensile strength, flexural strength, and water absorption, remained comparable to conventional concrete up to 15% replacement levels. The findings demonstrate that secondary aluminium dross serves as an effective supplementary cementitious material, maintaining concrete performance while potentially reducing environmental waste from aluminium production.

Pimchanok Puksisuwan et al. [2017] This research produced geopolymers from waste aluminium dross and bagasse ash. Materials were activated using sodium silicate and sodium hydroxide solutions via standard geopolymerization methods. Specimens were moulded and cured at room temperature for 3, 7, 14, and 28 days. Testing included compressive strength and thermal conductivity evaluation. SEM and FTIR analysis examined microstructural properties and chemical bonding. Results demonstrate successful conversion of industrial waste into sustainable construction materials.

Gireesh Mailar et al. [2016] Aluminium dross, a waste product from aluminium smelting operations, is typically processed for metal recovery before disposal as salt cake in landfills. This investigation explores its application as a cement replacement in concrete formulations optimised for hot climate construction. The research focused on evaluating the performance and durability of concrete incorporating recycled aluminium dross under elevated temperature conditions. Testing revealed that 20% cement replacement with aluminium dross extended initial setting time by approximately 30 minutes, providing enhanced workability for hot weather placement. Results indicate that 20% aluminium dross substitution delivers improved mechanical properties and durability performance compared to conventional concrete, making it a viable solution for hot climate construction while addressing industrial waste management.

Ing. Jan Sedo et al. [2015] Fine particles from aluminium dross processing create environmental challenges for companies in this sector. These particles are classified as waste based on their physical and chemical properties, requiring special handling. However, the same properties make them potentially valuable as raw materials for other industries. Processing aluminium dross and treating non-melting particle fractions is crucial for both waste producers and potential users of these materials.

Adeosun et al. [2014] This investigation analysed the physical and mechanical characteristics of aluminium dross. Dross concentrations varied from 50 to 90 wt.% with bentonite at 10-50 wt.% and fixed water content. Two particle sizes (106μm and 184μm) were examined with 10 samples each. Processing involved air drying (24 hrs at 31°C), oven heating (110°C for 24 hrs), and sintering (450°C for 8 hrs). Testing assessed volume shrinkage, porosity, density, compressive strength, and permeability. The 106μm particles showed maximum shrinkage (24%), porosity (15%), and density (1.9g/cc) but lower compressive strength (940 KN/m$^2$). Finer particles demonstrated 85% permeability compared to 70% for coarser particles due to agglomeration differences. Results indicate 106 μm dross bricks are suitable for acid-resistant refractories with properties similar to medium-alumina fireclay.

Bajare et al. [2013] This research investigated the potential for utilising non-metallic product (NMP) waste from aluminium scrap processing facilities to create lightweight expanded clay aggregates and concrete. NMP characterisation was previously documented by the authors (Bajare et al. 2012).

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.1, August : 2025

Laboratory simulation of aggregate production involved heating clay-waste combinations in a rotary furnace to 1200°C. Varying mixture compositions and heating temperatures resulted in expanded clay aggregates with diverse pore formations. The produced aggregates exhibited bulk densities ranging from 320 to 620 kg/m³. These different aggregate types were incorporated into lightweight concrete formulations. Standard testing procedures were applied to evaluate the mechanical properties, physical characteristics, and thermal conductivity of cured concrete samples.

## III. Conclusion

Based on the comprehensive literature review, it is evident that aluminium dross as an industrial waste material demonstrates significant potential as a partial cement substitute in concrete applications. The optimal replacement percentages typically range from 5 to 20% depending on processing techniques and concrete grade requirements, with numerous studies confirming enhanced mechanical performance and durability properties. This industrial by-product not only supports environmentally sustainable construction practices but also provides economic advantages while preserving or enhancing concrete quality standards. The combination of aluminium dross with supplementary cementitious materials such as bottom ash, phosphogypsum, and GGBS creates synergistic effects that improve composite behaviour, establishing new possibilities for green concrete technology advancement.

Based on the past research of the experts outlined above, many conclusions can be drawn:

- Optimal aluminium dross replacement ranges from 5 to 20% by weight of cement, with 15% showing superior performance in most studies.
- Compressive strength remains comparable to conventional concrete up to 15% replacement levels.
- Enhanced workability achieved through extended initial setting times, particularly beneficial for hot climate construction.
- Improved durability and corrosion resistance properties observed within specified replacement limits.
- Significant reduction in cement consumption and associated $CO_2$ emissions through industrial waste utilisation.
- Effective waste management solution for hazardous aluminium dross requiring costly disposal methods.
- Supports circular economy principles by converting problematic waste into valuable construction materials.
- Reduces dependency on natural resources while maintaining structural performance requirements.
- Lower raw material costs through aluminium dross incorporation compared to conventional concrete.
- Minimum selling price of USD 0.12/kg provides viable economic returns for industrial processing.
- Cost-effective alternative for sustainable construction material development.
- Potential for reduced construction costs while addressing environmental concerns.
- Heat treatment at 900°C enhances aluminium dross performance and removes harmful compounds.
- Mechanical milling and washing processes improve material characteristics and safety.
- Particle size optimisation (106 μm) delivers better mechanical properties and permeability.
- Proper characterisation essential for determining optimal replacement percentages.
- Promising material for lightweight concrete and specialised construction applications.
- Potential use in acid-resistant refractories with properties comparable to medium-alumina fireclay.

- Suitable for hot climate construction due to improved workability characteristics.
- Supports development of green concrete technologies and sustainable building practices.

**Statements and Declarations:**

Data Availability Statement:

Data supporting the study's conclusions are accessible from ResearchGate (https://www.researchgate.net) and DOI.org (https://doi.org) upon reasonable request.

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We, the authors of this review study, hereby confirm that no funding, grant, or other financial help was obtained to support the creation of this manuscript.

The authors state that they have no relevant financial or nonfinancial interests in the development or publication of this work.

Both authors were involved in the study's conception and design. Shivam Dwivedi handled material preparation, data collection, and analysis. Shivam Dwivedi wrote the first draft of the manuscript, while Dr Ravindra Gautam reviewed previous versions. Both authors have reviewed and approved the final manuscript.

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