International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Aluminum Dross as Sustainable Construction Material: A Review on Case Studies

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ABSTRACT—

Being a part of experimental investigation to mitigate the problems posed by aluminium dross in global perspective if used as landfill, various studies on micro-scale were done on aluminum waste coming from various industries across the globe to produce ceramics, mortar, cement, and concrete. The density, workability, water absorption, physical and chemical properties, mechanical properties, durability aspects including pore and microstructure studies are done to check the adequacy of the quantity of replacement. The aim of this article is to bring all the significant works done together either in fully or partially, aluminium dross / slag as a partial replacement to ingredients of the case considered, novice reviews, and observations, collectively analysed, synthesized, and summarized at one glance precisely. The published information on usage of aluminium dross in production of concrete which are in public domain has been elicited as a part of academic assessment. This may serve as a base for theoretical foundation for the main study and anchors the scope of the work to be carried out along with overview on current knowledge, relevant theories, gaps, and trends.

Keywords— Aluminium dross, concrete, mechanical properties, durability properties, porosity, and microstructure Introduction.

1. Introduction:

In the literature, there are several studies over the past 20 years to use this residue in construction applications as the replacement to sand or cement, to produce concrete blocks, to manufacture aluminate cement or as filler in asphalt products but research articles published on usage of aluminium dross are reviewed based on nature of work and few articles are assessed and documented after long refining process which have done significant contributions and critical in this segment. The results proved that the concrete products can be prepared by using the salt as the replacement for sand or cement without causing deleterious effects on concrete characteristics, and the calcium aluminate cement can be produced by using the salt cake as sources of CaO and Al2O3. It can be utilized by recycling and its re-usage reduces environmental contamination and exploitation of natural resources, thus resulting in an economic benefit.

Chronical usage of aluminium dross / slag in construction applications:

I. CHRONICAL USAGE OF ALUMINIUM DROSS IN CONSTRUCTION APPLICATIONS

A. From year 1997 - 2000

During this period most of the research focused on physical and chemical properties of the aluminium dross. Further, replacement of aluminum dross to cement has been done to mitigate the environmental issues and as a cost viable option. Aluminium waste has been used as a raw material for engineering applications like cement manufacturing, mortar and concrete.

The extensive research work proved that the replacement can be done to avoid the land filling. Studies conducted by O. Manfredi, W. With, I. Bohlinger, and other researchers delved into the analysis of the physical and chemical properties of aluminum dross, encompassing parameters like density, salinity, gas emissions, and alloy composition. An observation was made regarding the disparities between dense and granular dross, with the latter showcasing elevated levels of salinity and gas emissions. It was noted that the transformation of granular dross into a dense form takes place once the metal content reaches 70%.

Exploration into the realm of cement and mortar production was carried out by D.A. Pereira, Barroso de Aguiar, F. Castro, M.F. Almeida, J.A. Labrincha, Augustine U. Elinwa, and Elvis Mbadike, focusing on the utilization of aluminum-containing materials as partial replacements for sand or cement in the production of cement mortars and concrete. Their findings indicated that substituting slag with sand or cement yielded positive impacts on the mechanical properties, thereby offering economically viable and eco-friendly alternatives.

Diana Bajare, Aleksandrs Korjakins, Mareks Zakutajevs, and Filips Voroneko conducted research into the production of building materials by utilizing aluminum scrap recycling waste to fabricate expanded clay aggregates (ECA) and lightweight aggregates. These innovative materials boast distinctive characteristics such as high porosity, thereby contributing to the promotion of environmentally conscious construction practices.

A noticeable trend in the recycling sector involves the reprocessing of aluminum dross to extract metallic aluminum and aluminum oxides, consequently diminishing the necessity for landfill disposal, as emphasized by Dr. Evaggelia Petavratzi and fellow researchers. A comprehensive study carried out by A. Go´mez, N. B. Lima, and

J. A. Teno´rio centered on the quantitative analysis of white aluminum dross utilizing the Rietveld method, which yielded valuable insights into its composition and crystalline phases.

E.M.M. Ewais, N.M. Khalil, M.S. Amin, Y.M.Z. Ahmed, and M.A. Barakat dedicated their research to investigating the production of calcium aluminate cement through the utilization of aluminum sludge and slag as raw materials, showcasing its viability and compliance with international standards.

The treatment and disposal of residues stemming from aluminum dross recovery were scrutinized by K.E. Lorber and H. Antrekowitsch, shedding light on the significance of employing appropriate disposal techniques to avert the pollution of groundwater and the surrounding ambient air. Collectively, these research endeavors underscore the immense potential of aluminum dross as a valuable resource across diverse industries, presenting opportunities for waste minimization, financial savings, and the advancement of environmentally sustainable practices.

B. From year 2011 - 2024

The surge in research on aluminum dross and slag, particularly in their utilization as partial replacements for cement and sand, and their application in calcium aluminate cement production, indicates a worldwide trend towards waste reduction and sustainable practices across various industries. The extensive body of literature encompasses a myriad of perspectives and discoveries outlined in these scholarly inquiries:

In the realm of Aluminum Recovery Methods, scholars such as S. Maropoulos, D. Kountouras, X. Voulgaraki, S. Papanikolaou have dedicated their efforts to formulating mathematical models aimed at evaluating the efficiency of aluminum recovery techniques from dross. Their primary objective is to devise straightforward and effective methods that can be readily implemented in foundries, catering to the need for streamlined processes.

Delving into the realm of Enhancement of Mechanical Properties, the studies conducted by S. O. Adeosun, M. A. Usman, W. A. Ayoola, I. O. Sekunowo have ventured into enhancing the mechanical properties of polypropylene by integrating aluminum dross. Their research showcases notable enhancements in ultimate tensile strength and density, underscoring the potential for significant improvements in material characteristics.

Exploring Engineering Applications, Chen Dai has investigated the viability of repurposing aluminum dross waste for various engineering purposes, including the development of refractory materials, aluminum composites, and high-temperature additives for steel desulfurization. The findings indicate promising outcomes in terms of bolstering concrete strength and expanding the utility of aluminum waste in diverse industrial applications.

The development of Predictive Models by J.I. Arimanwa, D.O. Onwuka, M.C. Arimanwa, U.S. Onwuka utilizing Scheffe's theory to forecast the compressive strength of aluminum waste-cement concrete has introduced a time-efficient and cost-effective approach to mix design. This innovative method streamlines the concrete production process and enhances the overall efficiency of construction projects.

In the domain of Conversion of Hazardous Waste, Aurora Lopez- Delgado and Hanan Tayibi have presented a compelling case study on the conversion of hazardous aluminum waste into valuable materials such as glass, glass-ceramic, boehmite, and calcium aluminate. This transformative process underscores the potential for sustainable waste management practices, paving the way for innovative solutions in waste repurposing.

The Utilization in Cement Production, as explored by researchers like P.E. Tsakiridis, P. Oustadakis, S. Agatzini-Leonardo, sheds light on the utilization of black dross leached residue as a raw material for Portland cement clinker production. Their research demonstrates the feasibility and economic advantages of this approach over conventional disposal methods, marking a significant step towards sustainable resource management.

Effect of Aluminium dross on workability and setting times of cement and concrete by Panditharadhya B. J resulted into retardation of setting time and increased workability, as the percentage of aluminium dross in the mix increases, the setting time also increases, making it suitable for use in hot weather conditions. To balance the reduction in strength with increased binder replacement and meet workability requirements, it is recommended to replace only up to 20% of Ordinary Portland Cement with aluminium dross.

Concrete incorporating fly ash-15%, aluminum dross-10%, and quarry dust-20% showed better mechanical and durability characteristics compared to standard concrete. The aluminium dross has been replaced to cement and others to sand. The findings are showed improved mechanical and durability characteristics.

Studies on Impact on Concrete Properties, conducted by various researchers including Benjaporn Inseemeesak and Aphichart Rodchanarowan, have examined the effects of aluminum dross on the porosity and mechanical properties of cement paste. Their investigations offer valuable insights into how aluminum waste influences concrete performance, enriching our understanding of material behaviour and structural durability.

The study conducted by David O. Nduka and others investigated the influence of secondary aluminum dross (SAD) on the compressive strength and water absorption capacity properties of sandcrete blocks. Incorporating secondary aluminum dross (SAD) in sandcrete blocks can affect their compressive strength and water absorption capacity properties significantly.

Contributions by B. M. Mithun1, Shriram Marathe1, Gururaj Acharya, demonstrated the Incorporation of Aluminium dross in high-performance concrete resulted in a significant reduction in drying shrinkage by 1%. The use of Aluminium dross as an admixture in high-performance concrete showed potential for improving dimensional stability and reducing shrinkage cracking.

D. J. Arpitha, K.V.U. Praveen investigated the use of aluminium dross (AD) and ground granulated blast furnace slag (GGBS) as partial replacements for cement in concrete, aiming to optimize the percentage of these materials for maximum strength. Through various trial mixes, it was found that 5% of aluminium dross and 30% replacement of GGBS respectively provide the highest strength to the concrete, indicating the potential for eco-friendly concrete production. The discourse on Recycling Technologies spearheaded by scholars such as Arunabh Meshram, Ankur Srivastava, and others has explored emerging technologies for aluminum dross recycling. Emphasizing the importance of sustainable ecosystem practices and the development of efficient extraction methods for valuable products, their reviews underscore the significance of responsible waste management and the advancement of recycling technologies. Overall, these comprehensive studies underscore the multifaceted strategies employed in harnessing the potential of aluminum dross and slag, spanning from enhancing mechanical properties to reducing waste and fostering sustainable material production. These endeavors significantly contribute to the global initiatives aimed at environmental conservation and resource efficiency, marking a pivotal shift towards sustainable practices in industries worldwide.

Abbreviations and Acronyms:

AD - Aluminium dross; ASD – Secondary aluminium dross; AW - Aluminium waste; BAD – Black aluminium dross; BDLR - Black dross leached residue; BR - Bauxite residue; D – Density; DTA - Differential thermal analysis; ECA - Expanded clay aggregate; HAW – Hazardous aluminium waste; IR – Impact resistance; MSW - Municipal solid waste; MK - Metakaolin; NMP

- Non-metallic product; PP - Polypropylene; PPM - Particle parking

model; SEM - Scanning electron microscopy; TG - Thermal gravimetric; UTS – Ultimate tensile strength; WA – Water absorption; XRD - X-ray diffraction.

CONCLUSION:

The effective utilization of aluminum dross, whether it is white or black dross acquired from secondary aluminum processing industries, has been successfully demonstrated as a valuable raw material for the development of advantageous cementitious products, emphasizing its potential as a by-product when used in accordance with recommended guidelines. The extent to which aluminum slag can serve as a partial replacement varies depending on its source, as, durability properties fall within a similar range when compared to controlled samples, indicating a promising opportunity for integrating aluminum slag with other discarded by-products. This optimistic outlook could result in significant advancements, cost-effectiveness, and enhanced environmental sustainability across various industrial sectors. This positive outcome underscores the importance of exploring the full potential of aluminum dross in creating innovative and environmentally friendly solutions. It is evident that leveraging aluminum slag in cementitious applications can pave the way for a more sustainable and efficient industrial landscape. This highlights the need for further research and development in order to fully harness the benefits of utilizing aluminum dross in cement production, thereby contributing to a more circular economy and reducing environmental impact in the long term.

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