International Journal of Scientific Research in Engineering & Technology
Volume4, Issue2 (March-April 2024), PP: 102-105.
https://www.doi.org/10.59256/ijsreat.20240402014
www.ijsreat.com ISSN No: 2583-1240

Review on Advancements in the Production of Artificial Aggregates from Industrial Byproducts: A Sustainable Solution for Infrastructure Development

Noble Sahu[1], Vidhi Sahu[2], Manukant Dhruw[3], Kamal Paikra[4], Dr. Ajay Kumar Garg[5], Suprabha Panda[6]

[1,2,3,4] Department of Civil Engineering, Govt. Engineering College, Raipur, Chhattisgarh, India.
[5] HOD, Department of Civil Engineering, Govt. Engineering College, Raipur, Chhattisgarh, India.
[6] Assistant Professor, Department of Civil Engineering, Govt. Engineering College, Raipur, Chhattisgarh, India.

To Cite this Article: *Noble Sahu[1], Vidhi Sahu[2], Manukant Dhruw[3], Kamal Paikra[4], Dr. Ajay Kumar Garg[5], Suprabha Panda[6], "Review on Advancements in the Production of Artificial Aggregates from Industrial Byproducts: A Sustainable Solution for Infrastructure Development", International Journal of Scientific Research in Engineering & Technology Volume 04, Issue 02, March-April 2024, PP: 102-105.*

Abstract*:* *This review paper explores the burgeoning interest in artificial aggregates as sustainable alternatives to traditional construction materials, driven by concerns over resource depletion and environmental degradation. It comprehensively examines recent advancements, challenges, and future prospects in this field. Beginning with an overview of the imperative for alternative aggregates in construction, the paper discusses various types of artificial aggregates sourced from industrial by-products, recycled materials, and innovative manufacturing processes. It delves into their mechanical, physical, and environmental properties, contrasting them with natural aggregates, and evaluates the impact of production techniques like sintering, foaming, and chemical activation on their performance. Environmental sustainability aspects, including carbon footprint reduction and waste management, are rigorously analyzed, underscoring the potential of artificial aggregates to mitigate ecological impacts associated with conventional extraction and processing methods. Addressing hurdles to widespread adoption, such as technological barriers and economic viability, the review proposes strategies for overcoming these challenges and outlines future research directions to optimize artificial aggregates' properties and applications. In conclusion, this review offers valuable insights into the state-of-the-art developments in artificial aggregate technology, highlighting their pivotal role in advancing sustainability and resilience within the construction sector.*

Key Word: *Artificial aggregates, Sustainable construction materials, Environmental impact, Recycling, Waste utilization.*

I.INTRODUCTION

The burgeoning global urbanization and industrialization have triggered a surge in the demand for construction materials, particularly aggregates, essential for producing concrete, asphalt, and other building essentials. However, the extraction and processing of natural aggregates have posed significant environmental challenges due to resource depletion and carbon emissions. In response, researchers have turned their attention to sustainable alternatives, with a notable focus on repurposing industrial wastes. Notably, the utilization of fly ash and other byproducts from coal-fired power plants has emerged as a promising avenue for environmentally friendly aggregate production. Numerous studies, including those by Xiao et al. [1] and Bimo Brata Adhitya et al. [2], have investigated the synthesis of artificial aggregates from fly ash, revealing variations in physical properties based on different production techniques. Beyond fly ash, researchers have explored alternative industrial wastes and innovative manufacturing methods, such as fly ash cenosphere, sintered fly ash aggregate, and polymer matrix materials [6][7][8]. These endeavors have demonstrated the feasibility of integrating substitute aggregates into concrete mixes, achieving comparable mechanical properties to conventional concrete while mitigating waste disposal issues and preserving natural resources. Moreover, efforts to enhance the mechanical properties and sustainability of artificial aggregates through approaches like geopolymerization and the utilization of local industrial waste materials have shown promise [5][9]. This review aims to offer a comprehensive overview of recent advancements in artificial aggregate production from industrial byproducts, underscoring their potential to address environmental concerns and foster sustainable infrastructure development.

II.MATERIALS AND METHODS

In the realm of artificial aggregate production, various manufacturing techniques have been explored to harness different materials and processes. The following sections delineate the methodologies employed by different studies in the field:

Alkali Activation Method:

Bimo Brata Adhitya et al. utilized sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) as alkali activators in conjunction with Class C fly ash [1]. The process involved preparing an alkaline activator solution by mixing these chemicals in specific ratios. Subsequently, the prepared solution was dripped onto the fly ash in a granulator pan for pelletization. Alternatively, the mixture was molded and hardened before undergoing crushing [1].

Cold-Bonding Disk Granulation Technique:

Xiao et al. introduced a novel approach by employing Bacillus mucilaginous as a microorganism and waste concrete sand particles as the core material in a cold-bonding disk granulation technique [2]. This method facilitated the formation of artificial aggregates by inducing powder materials to form micronuclei under the influence of capillary action, leading to the growth of spherical particles within the powder layer [2].

Geopolymerization Process:

Hilda Yuliana et al. outlined a systematic process for artificial geopolymer aggregate production, maintaining specific mass ratios of fly ash to alkali activator and consistent Na2SiO3/NaOH ratios [3]. Their manufacturing process involved granulation using a granulator machine, with variations in slope to produce aggregates of different grain sizes [3].

Agglomeration Techniques for Lightweight Aggregates:

J.M. Bijen et al. categorized the production processes of lightweight aggregates from fly ash into sintering, autoclaving, or cold bonding methods [4]. Various agglomeration techniques such as agitation granulation, compacting, roll pressing, extrusion, and pellet mills were explored, each contributing to consolidating solid particles into larger shapes [4].

Laboratory-Scale Pelletization:

Shiva prasad et al. utilized laboratory-grade sodium silicate solution and sodium hydroxide flakes as alkali activators for fly ash geo polymer aggregate production [5]. Their manufacturing process involved pelletization in a laboratory disc pelletizer, followed by different curing regimes to assess aggregate properties [5].

Mixing and Heat Curing Process:

Chamila Gunasekara et al. employed Class F fly ash and sodium hydroxide solution for geopolymer stone production [6]. The materials were mixed, molded into cylindrical stones, and heat cured before being crushed into different sizes for testing [6].

Utilization of Various Materials in Concrete Mixes:

H.P. Satpathy et al. discussed the utilization of ordinary Portland cement (OPC), natural aggregates (NFA), crushed granite aggregates, fly ash cenosphere (FAC), and sintered fly ash aggregate (SFA) in concrete mixes [7]. Their study focused on preparing and testing various concrete mix compositions to evaluate their properties [7].

Melt Blending and Extrusion Process:

Scott Slabaugh et al. explored the production of synthetic lightweight aggregates (SLAs) using high carbon fly ash (HCFA) and plastics [8]. The manufacturing process involved melt blending, extrusion, granulation, and solidification to produce SLA particles with varying compositions [8].

Clay-Based Aggregate Production:

Wasan I. Khalil et al. employed Iraqi bentonite clay and sodium silicate as raw materials for artificial lightweight aggregate (LWA) production [9]. Their process encompassed raw material preparation, mixing, shaping, firing, and cooling to yield lightweight aggregates conforming to ASTM specifications [9].

III.RESULT

The review of recent studies on the production and utilization of artificial aggregates reveals promising advancements in the field, offering sustainable alternatives to natural aggregates for various construction applications. Key findings from the analyzed research include:

Aggregate Properties:

Pelletized aggregates exhibited sizes ranging from 2.36 mm to 12.5 mm, with a specific gravity average of 1.756, while crushed aggregates displayed adjustability in size and had a specific gravity of 1.863 [1].
Xiao et al.'s artificial aggregates showcased an apparent density of 2620 kg/m3, a crushing strength of 9.1 MPa, and a water absorption rate of 4.8% after 24 hours of curing [2].

Geopolymer artificial aggregates demonstrated specific gravities ranging from 1.69 to 1.87, with absorption rates varying between 4.17% and 11.55%, and hardness values ranging from 24.03% to 27.14% [3].

Mechanical Properties:

Artificial aggregates were found to possess high compressive strengths, ranging from 9.1 MPa to 23 N/mm2, depending on the production method and composition [2].

Aggregate replacement rates of up to 50% in concrete mixtures were reported without compromising mechanical integrity, indicating their potential as substitutes for natural aggregates [2].

Environmental Impact and Sustainability:

Utilization of waste materials such as fly ash, waste concrete powder, and sodium silicate industrial byproducts in aggregate production contributes to environmental sustainability and reduces carbon footprint [4].

Geopolymer-based aggregates offer eco-friendly alternatives, with lightweight properties, low permeability, and minimal shrinkage, meeting industry standards and reducing environmental impact [6].

Feasibility for Construction Applications:

Artificial aggregates demonstrated suitability for various construction applications, including concrete mixtures, lightweight concrete, road pavement, and structural members [3].

Studies highlighted the potential for artificial aggregates to meet structural requirements while utilizing hazardous thermal waste products and reducing environmental impact [7].

Challenges and Future Directions:

Despite promising results, challenges such as porosity, durability concerns, and reduced mechanical properties in lightweight concrete warrant further investigation [7]. Future research directions include exploring supplementary materials, optimizing production processes, and evaluating the long-term performance and durability of artificial aggregates in diverse environmental conditions [8]

The comprehensive review underscores the significant potential of artificial aggregates as sustainable alternatives to natural aggregates in construction applications. With their favorable mechanical properties, environmental benefits, and versatility for various construction needs, artificial aggregates offer a promising avenue for mitigating environmental impact and promoting sustainable development in the construction industry.

IV.DISCUSSION

The exploration of artificial aggregates for sustainable construction holds promise, yet challenges and opportunities for further research persist. Long-term studies assessing the durability of structures with artificial aggregates are needed to validate their performance. Enhancing production processes and investigating additives for improved properties are key areas for advancement. Diversifying materials beyond industrial byproducts could expand sustainable options. Quantifying carbon footprint reductions and addressing regulatory barriers are crucial for widespread adoption. Collaborative efforts are vital to realize the full potential of artificial aggregates in sustainable infrastructure development.

V.CONCLUSION

Conclusively, the research carried out by Bimo Brata Adhitya et al, Hilda et al, Bijen et al, and Shivaprasad et al jointly offer significant perspectives on the creation and properties of synthetic aggregates derived from fly ash. With an emphasis on water absorption, Adhitya et al.'s research highlights the significance of ratio control and processing techniques in obtaining desirable aggregate qualities. The work of Hilda et al. emphasizes the importance of curing techniques and granulator parameters in maximizing aggregate strength, with heat curing showing encouraging outcomes. The results of Bijen et al. highlight the various ways that artificial aggregates are manufactured, with different factors like compaction and coal content taken into account. The study by Shivaprasad et al. shows how processing variables and water content affect aggregate strength and highlights the use of fly ash geopolymer aggregates in concrete applications. When taken as a whole, these research expand our understanding of how to use fly ash as a sustainable substitute for aggregate production, which has implications for sustainable building materials and the environment. Additional studies in this area might look on long-term performance in real-world scenarios as well as optimization tactics for particular applications.It is clear from the research done by Wasan I. Khalil et al., Satpathy et al., and Chamila Gunasekara et al. that different methods of producing lightweight aggregate (LWA) provide encouraging outcomes for environmentally friendly building techniques. According to Gunasekara's study, it is feasible to produce high-strength LWAs with remarkable mechanical and durability qualities by employing particular compression procedures. Satpathy's research focuses on lightweight concrete formulations that are environmentally benign by using aggregates made of sintered fly ash and fly ash cenospheres. Though there are certain durability concerns, the promise for structural lightweight concrete is evident, even though mechanical qualities may decline with more substitution. In order to create LWAs, Khalil's research investigates the use of waste sodium silicate and bentonite clay from Iraq. This approach results in concrete with remarkable mechanical qualities and economical, ecologically friendly production processes. All of these studies highlight how lightweight concrete and aggregates can be used to build sustainably, providing advantages for the economy, the environment, and construction performance that call for more research and use in building techniques.

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