International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-12, Issue-4; Apr, 2025
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.124.1

Exploring the Potential of Recycled Aggregates in Modern Construction Challenges and Innovations

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Received: 21 Feb 2025,

Receive in revised form: 20 Mar 2025,

Accepted: 25 Mar 2025,

Available online: 01 Apr 2025

***Keywords*— Construction Materials, Natural Aggregates, Sustainable Alternatives, Recycled Aggregates.**

***Abstract*— *The reliance of the construction industry reliance on natural aggregates has led to significant environmental concerns, including resource depletion and habitat destruction. This paper explores the potential of recycled aggregates as sustainable alternatives to natural materials, emphasizing their environmental and economic benefits. It provides a comprehensive review of various types of recycled aggregates, their extraction processes, associated challenges, and recent innovations to improve their applicability. Key findings highlight the effectiveness of advanced treatment techniques and material modifications in enhancing the performance of recycled aggregates. The paper concludes with recommendations for future research and standardization efforts, aiming to integrate recycled aggregates into mainstream construction and contribute to a more sustainable built environment.*

I. INTRODUCTION

The worldwide building sector has been acknowledged for a time as a major user of natural resources. Aggregates, like sand and crushed stone play roles in the creation of concrete and asphalt. [1,2]. Nevertheless, the continuous utilization of these resources has resulted in notable environmental issues such as habitat loss and water contamination along with the exhaustion of natural reserves, leading to a surge in interest towards sustainable building methods in recent times [3,4].

Government rules and policies encourage the usage of eco friendly materials in building projects within the ASEAN region. ASEAN's governments plan to boost this construction methods by providing financial aid for using environmentally friendly materials such as supplementary cementitious materials (SCMs) and recycled aggregates. The goal of these efforts is to decrease non-renewable resource usage and waste generation while also lessening harm to the environment and simultaneously support sustainable economic growth and social welfare in the long run [5].

The market size of the construction and demolition sector reached $100.5 billion in 2022. It is anticipated that this industry will expand from $105.72 billion, in 2023 to $158.60 billion by 2032 showing a compound growth rate (CAGR) of 5.20% between the years 2023 and 2032. Factors such, as urbanization population increase and infrastructure investments are driving market growth significantly [6].

Recycled materials have become a choice, for infrastructure development bringing both environmental and economic advantages. The uses of these materials in construction are wide ranging from incorporating them into production to building roads and more. One key application is using recycled materials to make concrete. Research indicates that these materials can substitute ones in mixes leading to a notable decrease, in the environmental effects of making concrete. This switch not helps preserve resources but also lessens the carbon footprint related to extracting and processing new materials [7,8].

Fig.1. Forecast of market size of the construction and demolition sector [6].

Recycled aggregates are utilized alongside concrete, in road construction in the layers of roads. These materials offer strength and longevity. This application is particularly beneficial in urban areas where construction and demolition waste is abundant aiding in waste disposal and lessening the demand, for landfill space [9,10]. Recycled materials are also used in building embankments and retaining walls. Incorporating them into these structures can enhance stability minimize erosion risks and offer an eco substitute, for materials [11]. Recycled aggregates are also suitable, for making items precaste concrete such as blocks and pavers which play a crucial role in urban infrastructure [12]. Furthermore, incorporating recycled aggregates, into concrete can improve characteristics like insulation and sound absorption making it ideal, for a range of construction purposes [13]. Moreover incorporating recycled aggregates, in road building can result in reduced costs since they are typically more economical, than aggregates [14].

The analysis of chemicals showed that all the recycled aggregates tested (recycled concrete aggregate (RA-Con), recycled ceramic aggregate (RA-Cer), and mixed recycled aggregate (RA-Mix) did not have any substances surpassing the specified limits set by regulations confirming their suitability, for being used as construction materials [15].

II. TYPES OF RECYCLED AGGREGATES

Recycled materials come from origins each adding distinct features to the properties of the material. It is essential to comprehend these origins to evaluate the possibilities and constraints of using recycled materials, in construction. The main origins consist of waste from construction and demolition by products, from industries and reused asphalt pavement.

In the construction sector used recycled materials include recycled Concrete aggregates (RCA) recycled masonry aggregates (RMA) mixed recycled aggregates (MRA) and reclaimed asphalt pavement (RAP) [16]. (Pereira & Vieira, 2022).

III. EXTRACTION OF RECYCLED AGGREGATES

There are few ways of past researchers extracting the reycled aggregates from demolition site. Generally, the whole process of extracting recycled aggregate involves sorting and segregating the waste materials, crushing and screening aggregates and lastly testing the quality of the recycled aggregates [17].

The process starts by gathering and choosing CDW materials, which are then tested in ways to confirm they meet the required standards. These tests cover aspects such, as composition, particle sizes, density, water absorption, shape and also include checks for pollutants [18]. Once the suitability of the CDW is confirmed the next phase includes treating the waste to generate RA. This can be done using techniques, like the two stages jigging process, which efficiently isolates impurities such, as ceramics and mortar thus improving the grade of the RA [19]. Moreover, by utilizing materials and implementing pretreatment methods it is possible to enhance the characteristics of recycled aggregates (RA) thereby improving its ease of use, strength and longevity for structural purposes. It is advised to follow a revised mixing method and determine the levels of replacing cementitious materials to attain the desired quality in concrete [20].

IV. PAST RESEARCH

The studys results show that the production of mixed recycled aggregate (MRA), from construction and demolition waste leads to a 70.66% reduction in environmental effects compared to the production natural aggregates obtained from a quarry. Furthermore, the economic assessment showed that production of recycled aggregates costs 30% less than using natural aggregates. The procedure of this research adhered to the four stages detailed in the ISO 14040;2021 encompassing Goal and Scope of the Study, Life Cycle Inventory, Impact Assessment, and Interpretation [7].

Reactive areas are a place that characterized by soil that undergoes volume changes in response to moisture fluctuations. Therefore, it causes a challenge for installing infrastructure such as pipelines and buildings in this area. The research evaluated the effectiveness of using recycled materials to stabilize soil zones by examining changes in ground deformation over time. The research employed

InSAR methods to observe changes, in the ground of a sewer pipeline trench filled with recycled materials, in Melbourne, Australia between October 2020 to February 2022 (17 months). The test reported that although not eliminating the movement entirely, the recycled materials helped in stabilizing the ground by reducing the extent of movements [13].

By utilizing 25% of incinerated ash (IBA) and adding 40% copper slag, the strength of high-performance concrete (HPC) can be boosted. Moreover, incorporating recycled coarse aggregate (RCA) in self compacting HPC allows for replacing up to half of the aggregate without compromising durability characteristics [10].

V. CHALLENGES

Recycled aggregates, despite their sustainability benefits, face numerous challenges that hinder their widespread adoption. These challenges include variability in quality, mechanical performance limitations, and a lack of standardized testing procedures. Addressing these issues requires.

Table 1 summarizes each challenges faced by different types of recycled aggregates and limitations respectively.

Table.1: Limitation of Different Types of Recycled Agrregates

Type of Recycle Aggregate	Limitation	Author
Recycled Concrete Aggregates (RCA)	The paper mentions that recycled aggregates may exhibit slightly inferior characteristics compared to natural aggregates in terms of porosity, friability, and variability, indicating a limitation in the quality of recycled materials. It is highlighted that there is currently no specific standard for measuring the water absorption of recycled aggregates, which poses a limitation in accurately assessing this important property. The use of recycled aggregates in concrete results in a significant drop in compressive strength compared to control concrete without recycled aggregates.	[21]
Recycled Construction and Demolition waste (CDW	(CDW) as aggregates, in making concrete resulted in water absorption and apparent porosity along with density and mechanical strength (such as compressive strength and tensile splitting strength). The research emphasized that the irregular shapes and fragile particles of CDW materials like ceramics, concrete, mortar, among others weakened the concretes durability.	[22]
RCA	A key issue revolves around the inconsistency in the quality of reused materials impacting the effectiveness of the end result. This inconsistency typically arises from the composition of construction and demolition debris, which may comprise materials like concrete, bricks and asphalt	[23]
RCA	Incorporating recycled aggregates in concrete production reduces the Life Cycle Cost (LCC) compared to using natural aggregates.	[24]
Recycled Construction and Demolition waste (CDW)	The physical and chemical characteristics of recycled aggregates, from construction and demolition waste varied from each other resulting in a challenge that restricts their application in producing construction materials. A notable drawback in the manufacturing process is the abundance of fines in the recycled aggregates resulting in a high modulus of fineness that influences the aggregate properties.	[15]

VI. INNOVATION

In order to tackle this problem, it is essential to conduct a quality control procedures and conduct standardized testing procedure to ensure the reliability of recycled aggregates for construction purposes [25]

The research discovered that Recycled Aggregate Concrete (RAC) exhibits lower strength levels than Natural Aggregate Concrete (NAC). However, by substituting only 40% of aggregate, percentage replacement that have been identified as the optimal replacement percentage that maintains strength. Furthermore, introducing either 1.5% of Polypropylene (PP) fiber or 1.25% of recycled PP fiber into RAC enhances its performance and achieves optimal strength levels. Polypropylene (PP) fibers are one of the cheapest fibers compared to other fibers such as steel, glass, and synthetics and are also widely available [24].

The research papers findings suggest that incorporating crushed old concrete (COC) as recycled fine aggregate (RFA) in polymer reactive powder concrete (PRPC) can improve the tensile and flexural strengths of the concrete. The research indicates that the mixture containing 40% COC replacing aggregate (NFA) demonstrates the highest levels of compressive strength, tensile strength and flexural strength both before and after exposure to various liquids, like water, fresh oil and used engine oil [9].

Using recycled aggregates, in infrastructure construction has proven to be effective because they can maintain fracture characteristics and performance, as regular concrete when combined with steel fibers. The studys results suggest that steel fiber reinforced concrete made with recycled aggregate exhibited performance and fracture characteristics to concrete. Additionally, it displayed enhanced fracture properties. Decreased brittleness as the steel fiber content increased [11].

The research papers findings suggest that when the recycled brick aggregate (RBA) replacement rate increases, the strength of RBA decreases. However, this decrease can be effectively countered by incorporating polypropylene fiber (PPF) and nano silica (NS) into the mix (PPF NS). The study revealed that PPF NS concretes frost resistance compared to concrete as indicated by improved visible characteristics, reduced mass loss and strength preservation following freeze thaw cycles. Moreover the microstructure of PPF NS modified RBA concrete was denser, with a fractal dimension in its cross section both before and, after freeze thaw cycles [12].

Recycled materials, like recycled aggregates (CRAs) and processed recycled aggregates (PCRAs) have shown potential in improving the longevity of alkali activated concrete (AAC) for sustainable infrastructure. The research revealed that AAC experienced an increase in strength reaching 65.9 MPa after being exposed to seawater for 90 days demonstrating durability. Examination of the microstructure and after durability tests indicated that AAC with PCRAs displayed polymerization due, to a higher presence of alumino silicate gel leading to improved performance [25].

Recycled concrete aggregates (RCAs) are commonly obtained from construction and demolition waste helping to reduce waste in the industry. Utilizing coarse recycled aggregates (CRCA) is essential, for creating eco concrete. Their role in the construction field is significant as they provide an alternative to aggregates contributing to waste reduction and environmental sustainability efforts. However, the effectiveness of CRCA in concrete may decline when higher replacement rates are used due to the presence of mortar. Implementing treatments such as washing, drying and carbonation can alleviate these drawbacks highlighting CRCAs importance as an asset, for the construction industry [26].

In the research adding recycled aggregate (RCA) to asphalt mixes showed great improvement of properties when combined with waste alumina. This method not efficient to handle waste management concerns but also boosts the overall performance of asphalt mixtures. Replacing 20% of conventional filler with secondary aluminum dross (SAD) in the mixture containing recycled concrete aggregate (RCA) at different rates improved the tensile strength ratio (TSR) by 8.52% and the index of retained strength (IRS) by 13.42%. Optimal resistance to moisture damage was achieved with a 25% RCA content in the mixture. Treating the RCA with acid resulted in increased stability by an average of 5.8 and reduced Marshall flow by 3 [14].

Ferrández et al.,(2023) introducing 2 steps of treating the recycled aggregate which are Washing and Secondary Crushing. The objectives of washing stage are reducing fine and impurities content, and also reducing the water absorption coefficient. The Secondary Crushing stage on the other hand was introduced to increase the amount of material recovery.

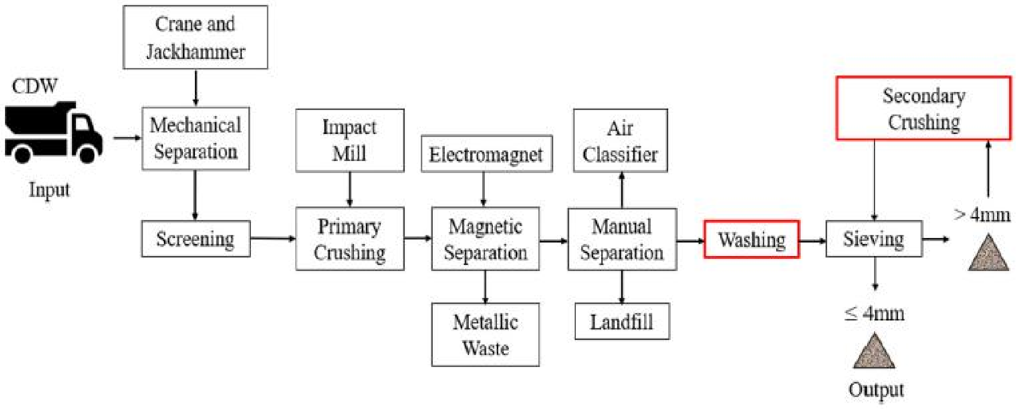

Figure 2. Manufacturing system of Recycled Aggregates with the addition of the secondary crushing and sand washing stages [17].

Although the quality of treated recycled aggregate still inferior compared to natural aggregate, the results of introducing of these two (2) stages still led to satisfactory results ; the compressive strength and flexural strength of end product which was mortar shows improvement compared to the end product that are incorporating untreated aggregate. Flexural strength of final product increased by 5% while compressive strength increased by 6% when the treated aggregates were incorporated compared to when untreated aggregates were used [17].

VII. CONCLUSION

Recycled aggregates offer diverse potential for promoting sustainability in construction by addressing environmental challenges like resource depletion and waste management. Despite challenges such as inconsistent quality and lower mechanical performance, innovations in treatment and innovative material combinations have demonstrated promising results.

ACKNOWLEDGEMENTS

The authors acknowledge the support of Grant named Development of High Volume Manganese Slag for Modified Brick as Sustainable Construction Materials under Grant Number UTS/RESEARCH/<4/2023/10>(01) provided by University of Technology Sarawak, which facilitated the submission of this paper for publication

REFERENCES

[1] Bekkeri, G. B., Shetty, K. K., & Nayak, G. (2023). Synthesis of artificial aggregates and their impact on performance of concrete: a review. *Journal of Material Cycles and Waste Management*, *25*(4), 1988–2011. https://doi.org/10.1007/s10163-023-01713-9

[2] Rasool, D. A., Al-Moameri, H. H., & Abdulkarem, M. A. (2023). Review of recycling natural and industrial materials employments in concrete. *Journal of Engineering and Sustainable Development*, *27*(2), 180–195. https://doi.org/10.31272/jeasd.27.2.3

[3] Alam Bhuiyan, M. M., & Hammad, A. (2023). A hybrid multi-criteria decision support system for selecting the most sustainable structural material for a multistory building construction. *Sustainability (Switzerland)*, *15*(4). https://doi.org/10.3390/su15043128

[4] Moshood, T. D., Rotimi, J. O. B., & Shahzad, W. (2024). Enhancing sustainability considerations in construction industry projects. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-04946-2

[5] Liong, R., Puspitasari, S. D., Binhudayb, F. S., & Hesham, S. (2024). Advancements in green materials for concrete in South East Asia: A mini review. *Tropical Environment, Biology, and Technology*, *2*(1), 44–56. https://doi.org/10.53623/tebt.v2i1.441

[6] Market Research Future. (2023). Global construction and demolition market overview. Retrieved January 16, 2025, from https://www.marketresearchfuture.com/reports/construction-demolition-market-12597#:~:text=Global%20Construction%20And%20Demolition%20Market%20Overview&text=The%20construction%20and%20demolition%20industry,period%20(2023%20%2D%202032).

[7] Linares, R., López-Uceda, A., Piccinali, A., Martínez-Ruedas, C., & Galvín, A. P. (2024). LCA applied to comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources. *Environmental Science and Pollution Research*, *31*(31), 44023–44035. https://doi.org/10.1007/s11356-024-33868-9

[8] Yosri, A. M., Azam, A., Alanazi, F., Alshehri, A. H., & Okail, M. A. (2024). Shear strength and particle breakage of construction and demolition waste as a function of moisture state and compaction level: Insights for sustainable highway engineering. *PLoS ONE*, *19*(3), 1–19. https://doi.org/10.1371/journal.pone.0298765

[9] Hasan, S. S., & Fattah, M. Y. (2023). Strength properties of polymer reactive powder concrete with waste materials. *Civil Engineering Journal (Iran)*, *9*(8), 1936–1956. https://doi.org/10.28991/CEJ-2023-09-08-09

[10] Jasim, A. M. D. A., Wong, L. S., Kong, S. Y., Al-Zand, A. W., & Midhin, M. A. K. (2023). An evaluative review of recycled waste material utilization in high-performance concrete. *Civil Engineering Journal (Iran)*, *9*(11), 2927–2957. https://doi.org/10.28991/CEJ-2023-09-11-020

[11] Maglad, A. M., Mansour, W., Tayeh, B. A., Elmasry, M., Yosri, A. M., & Fayed, S. (2023). Experimental and analytical investigation of fracture characteristics of steel fiber-reinforced recycled aggregate concrete. *International Journal of Concrete Structures and Materials*, *17*(1). https://doi.org/10.1186/s40069-023-00637-w

[12] Gong, S., Wang, T., Hasan, M. M., Mei, X., Tan, Z., Su, T., & Cao, F. (2023). Effect of polypropylene fiber and nano-silica on the compressive strength and frost resistance of recycled brick aggregate concrete. *Nanotechnology Reviews*, *12*(1). https://doi.org/10.1515/ntrev-2023-0174

[13] Teodosio, B., Al-Taie, A., Yaghoubi, E., & Wasantha, P. L. P. (2023). Satellite imaging techniques for ground movement monitoring of a deep pipeline trench backfilled with recycled materials. *Remote Sensing*, *15*(1). https://doi.org/10.3390/rs15010204

[14] [14] Ugla, S. K., & Ismael, M. Q. (2023). Evaluating the moisture susceptibility of asphalt mixtures containing RCA and modified by waste alumina. *Civil Engineering Journal (Iran)*, *9*, 250–262. https://doi.org/10.28991/CEJ-SP2023-09-019

[15] Saiz Martínez, P., Ferrández, D., Melane-Lavado, A., & Zaragoza-Benzal, A. (2023). Characterization of three types of recycled aggregates from different construction and demolition waste: An experimental study for waste management. *International Journal of Environmental Research and Public Health*, *20*(4).

https://doi.org/10.3390/ijerph20043709

[16] Pereira, P. M., & Vieira, C. S. (2022). A literature review on the use of recycled construction and demolition materials in unbound pavement applications. *Sustainability (Switzerland), 14*(21). https://doi.org/10.3390/su142113918

[17] Ferrández, D., Saiz, P., Zaragoza-Benzal, A., & Zúñiga-Vicente, J. A. (2023). Towards a more sustainable environmentally production system for the treatment of recycled aggregates in the construction industry: An experimental study. *Heliyon, 9*(6). https://doi.org/10.1016/j.heliyon.2023.e16641

[18] Naim, A., Hattab, I., Zahnoune, R., Elghozlani, M., Tanane, O., El Bouari, A., & Elkacmi, R. (2024). Assessing the feasibility, usability, and durability of recycled construction and demolition waste in road construction in Morocco. *Materials Research Proceedings, 40*, 19–32. https://doi.org/10.21741/9781644903117-3

[19] Gschwenter, V. L. S., Tubino, R. M. C., Ambrós, W. M., Miltzarek, G. L., Sampaio, C. H., Moncunill, J. O., Cazacliu, B. G., & Dal Molin, D. C. C. (2022). Production of high-quality coarse recycled aggregates through a two-stage jigging process. *Minerals, 12*(5). https://doi.org/10.3390/min12050532

[20] Joseph, H. S., Pachiappan, T., Avudaiappan, S., Maureira-Carsalade, N., Roco-Videla, Á., Guindos, P., & Parra, P. F. (2023). A comprehensive review on recycling of construction demolition waste in concrete. *Sustainability (Switzerland), 15*(6). https://doi.org/10.3390/su15064932

[21] Chaabane, L. A., Soualhi, H., Fellah, I., Khalfi, Y., & Bouayed, N. S. (2024). Physical and mechanical behaviour of recycled concrete under destructive and non-destructive testing. *Budownictwo i Architektura, 23*(2), 37–57. https://doi.org/10.35784/bud-arch.5840

[22] Contreras Llanes, M., Romero Pérez, M., Gázquez González, M. J., & Bolívar Raya, J. P. (2022). Construction and demolition waste as recycled aggregate for environmentally friendly concrete paving. *Environmental Science and Pollution Research, 29*(7), 9826–9840. https://doi.org/10.1007/s11356-021-15849-4

[23] Wang, Y., Liang, J., Wang, C., & Li, W. (2024). Axial compression behavior of carbon fiber reinforced polymer confined partially encased recycled concrete columns. *PLoS ONE, 19*(6). https://doi.org/10.1371/journal.pone.0304797

[24] Tenzin, R. Y., Drakpa, L., Deki, T., Subba, S., Norbu, C., Kuenchap, P., & Chimmi. (2023). Recycled aggregate concrete (RAC): A viable solution for sustainable construction. *Journal of Applied Engineering, Technology and Management, 3*(1), 63–69. https://doi.org/10.54417/jaetm.v3i1.111

[25] Khan, M. I., Ram, V. V., & Patel, V. I. (2024). Durability performance of alkali-activated concrete with pre-treated coarse recycled aggregates for pavements. *Scientific Reports, 14*(1), 1–16. https://doi.org/10.1038/s41598-024-64506-6

[26] Kareem, A., & Sahoo, D. K. (2024). Review on the importance of coarse recycled concrete aggregates as alternative construction materials. *Advanced Materials in Civil Engineering, 51–64*. https://doi.org/10.55084/grinrey/rtm/978-81-964105-5-1_4