Diversifying Aggregate Sources in Northern Nigeria: A Review of Alternative Materials

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Abstract

The demand for aggregates in concrete production is high, especially in developing countries, but their supply faces challenges. This has led to the exploration of alternative materials to replace naturally occurring aggregates. While traditionally, natural sources have been the primary supplier, concerns about environmental impacts have prompted the consideration of recycled aggregates and other secondary materials. However, the adoption of these alternatives remains limited. This research aims to assess the awareness and barriers to the adoption of alternative materials. It utilized quantitative methodology, collecting data from previous studies on potential alternatives at Ahmadu Bello University, Zaria. Additionally, a survey using structured questionnaires was conducted among 25 contractors registered with the Gombe State Ministry of Works, Housing, and Urban Development. The study identified 36 research studies on alternative materials. Several materials were found to have the potential to replace natural aggregates, including palm kernel shell, crumb rubber, glass cullet, plastic waste, burnt bricks, broken tiles, polystyrene, charcoal, recycled aggregate, sawdust, and date seeds. The findings revealed that a majority of the contractors (70%) were aware of these alternative materials, but they had not yet incorporated them into their projects. The low adoption was attributed to factors such as project complexity, limited knowledge about the materials, and client requirements. In conclusion, this research recommends the implementation of awareness campaigns to educate contractors and clients about the availability and potential benefits of alternative aggregate materials in construction. By addressing these barriers and increasing awareness, the construction industry can embrace alternative materials, contributing to more sustainable practices.

Keywords: Alternative aggregate, Building contractors, Natural aggregates, Sustainability.

INTRODUCTION

Concrete, as a widely used construction material, has experienced significant growth due to its advantages in terms of durability, fire resistance, affordability, strength, and thermal insulation (Mehta and Monteiro, 2014). However, its extensive use has led to substantial consumption of natural resources, particularly aggregates, resulting in environmental concerns (Tafazzoli, 2016).

With the increasing demand for infrastructure and urbanization, construction activities have grown exponentially, leading to a significant exploitation of natural resources for concrete production (Srivastava et al., 2015). The annual consumption of concrete materials, including cement and aggregates, has exceeded 30 billion tons since 2013 (Mehta and Monteiro, 2014). This high demand for aggregates is a matter of concern, given that it accounts for 70-80% of concrete volume, with global consumption estimated at approximately 48.3 billion metric tons per year (Mohammed and Najim, 2020).

In light of these challenges, researchers have explored alternative materials to natural aggregates. Recycled concrete, burnt clay bricks, recycled aggregates, palm kernel shell, and broken tiles have been identified as potential alternatives, either as partial or full replacements for conventional aggregates. However, the adoption of these alternative materials remains limited. Therefore, this paper aims to identify the barriers to the adoption of alternative aggregate materials in place of conventional aggregates. By understanding these barriers, strategies can be developed to promote the wider utilization of alternative materials, contributing to the sustainability of concrete production.

METHODOLOGY

This research aims to identify the barriers to the adoption of alternative aggregate materials as substitutes for conventional naturally occurring rock aggregates. The research approach employed is descriptive in nature, as it seeks to provide a comprehensive description of specific phenomena (Kumar, 2011). According to Kumar, descriptive research can be either qualitative or quantitative, depending on the research questions posed. In this study, which aims to answer questions related to "what" and "how," a quantitative inquiry approach is adopted (Creswell, 2013).

The research methodology involved collecting data from two sources. Firstly, secondary data was gathered from previous studies conducted in the Departments of Building and Civil Engineering at Ahmadu Bello University, Zaria, Nigeria. These studies identified a total of 14 materials capable of replacing naturally occurring aggregates, either partially or entirely, in concrete production. These materials were documented in 36 research papers.

Secondly, primary data was obtained through a questionnaire survey, which focused on determining awareness and barriers to the adoption of the identified alternative aggregate materials. The survey was conducted in Gombe state, located in the North-East region of Nigeria. A total of 25 contractors registered with the Gombe State Ministry of Housing and Urban Development were selected as participants and provided with structured questionnaires. The questionnaires were completed by professionals working in construction companies. All 25 questionnaires were filled out and returned. Subsequently, the data from the questionnaires was analyzed and presented in the form of tables and charts.

Finally, this study employs a quantitative research design to identify barriers to the adoption of alternative aggregate materials. Secondary data from previous studies and primary data from a questionnaire survey were collected and analyzed to provide insights into the awareness and obstacles associated with the use of alternative aggregates in the construction industry.

RESULTS AND DISCUSSIONS

Alternative Materials to Conventional Naturally Occurring Rock Aggregate

One objective of this paper is to identify available materials that have been researched and found to possess sufficient characteristics for partial or full replacement of naturally occurring stone aggregate.

Palm Kernel Shell

Palm kernel shell concrete is the most extensively studied alternative material in the study area. A total of seven research studies on the performance of palm kernel shell as an aggregate material were found in the school library. A Google Scholar search for "Palm kernel shell as aggregate material" yielded 13,200 results, indicating significant global research interest in this material in recent times. Palm kernel shell is abundantly available as a waste material in Northern Nigeria, primarily in the middle belt region where palm trees are cultivated.

Researchers worldwide have reported promising results regarding the use of palm kernel shell as an aggregate material, either as a partial or complete substitute for natural aggregate in concrete production. Eziefula and Anya (2017) conducted experiments using palm kernel shell as a fine aggregate in concrete mixtures and reported a compressive strength of 14.02 N/mm² at 28 days. Fanijo, Babafemi, and Arowjulu (2019) investigated the substitution of natural coarse aggregate with palm kernel shell at 10%, 20%, and 30% and recorded 28-day compressive strengths of 38 N/mm², 36 N/mm², and 35 N/mm², respectively. Consequently, the researchers recommended the use of palm kernel shell as an aggregate material in concrete production.

Glass Cullet

Waste Glass Cullet (WGC) is a by-product of glassworks and glass waste in the form of bottles and other glass containers. Every year, several thousand tons of waste glass are generated from glass cutting, waste bottles, and other industrial processes. Lu and Poon (2019) reported that approximately 300 tons of waste glass were produced daily in Hong Kong in 2016, with only 7.7% of it being recycled.

The use of WGC as an aggregate in concrete production has gained significant research interest both locally and globally. Five research studies on the application of WGC as concrete aggregate were found in the study area's library, and a Google Scholar search for "Glass cullet as concrete aggregate" yielded 12,300 results. Therefore, the use of WGC as an aggregate in construction is extensively researched globally, with promising results.

Lu and Poon (2019) replaced the fine aggregate in concrete mixes with WGC at percentage ratios of 25%, 50%, 75%, and 100% and obtained 28-day compressive strengths (N/mm²) of 31, 30, 25, and 25, respectively. Similarly, Malek, Lasica, Jackowski, and Kadela (2020) replaced natural fine aggregate with WGC at percentages of 5%, 10%, 15%, and 20% and reported 28-day compressive strengths (N/mm²) of 55, 50, 40, and 30, respectively. These findings indicate that WGC can be used as a replacement for naturally occurring stone aggregate in concrete production.

Crumb Rubber

Crumb Rubber (C.R) is a waste rubber recycled from used vehicle tires. It is an eco- friendly method of disposing waste vehicle tires (Hesami, Salehi and Emadi, 2020). CR is produced through processing of scrap tire by crushing, grinding, separation and screening. Scrap rubber is a global waste problem since waste vehicle tires can be found in most cities and towns around the globe. In northern Nigeria, Waste rubber tires can be found in spare parts markets, along major roads dumped as refuse, in mechanic and vulcanization shops.

However, researches have been conducted which shows the viability of CR as an aggregate material. Four researches were found on the use of crumb rubber as concrete aggregate material in the study area, While Google scholar search of ‘’ Crumb Rubber as concrete aggregate’’ returned a total of 3,360 results. Therefore, this shows that application of CR as aggregate in concrete production is also a well-researched area globally.

Hesani, et al (2016) replaced naturally occurring aggregate with CR in a percentage ratio of 5,10 and 15 using Water cement ration of 0.39 and recorded a 28days compressive strength (N/mm^2) of 67, 60 and 55 respectively. Aslani and Asif (2020) in separate experiments replaced both Fina and Coarse aggregates with CR in a percentage ration of 10 and 30 and reported 28 days' compressive strength (N/mm^2) of 27 and 27 where CR replaced fine aggregate, and 27 and 25 for the mix where CR was used as partial replacement of Coarse aggregate. Hence, Crumb Rubber is a viable aggregate material which can be used to replace both fine and coarse aggregate in concrete production.

Plastic Waste

Waste from plastic materials such as Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE) and Polypropylene (PP) are another waste material which can be used as aggregate material in concrete production (Abu Saleem et al.,2021). Plastic waste materials include waste plastic bottles and other waste plastic containers, components and parts. Plastic waste constitute one of the most common urban pollutants globally (Belmokaddem. et al, 2020). Consequently, researchers investigated the possibility of using plastic waste as aggregate material in concrete production. In the study area, a total of 4 researches were found on the use of plastic waste as replacement of aggregate in concrete production., while a Google scholar search ‘’ Plastic waste as aggregate in concrete’’ returned a total 11, 200 results. This result shows that the use of plastic waste as aggregate material is a researched topic both globally and locally in the study area.

Various researchers have experimented the use of plastic waste as aggregate materials in concrete production with encouraging results.

Belmokaddem, et al (2020) replaced fine aggregate in percentage ration of 25, 50 and 75 with waste PVC plastic waste and reported a 28days compressive strength (N/mm^2) of 26, 22 and 16 , while Abu Saleem et al (2021) replaced naturally occurring stone aggregate with HDPE plastic in percentage ratio of 10,20 and 30 and reported a 28 Days compressive strength of (N/mm^2) of 25.7, 19.9 and 19.2. Therefore, this shows that various kind of plastic waste can be utilized as aggregate material to replace partially occurring stone aggregate.

Burnt Bricks

Burnt brick are broken or over burnt bricks which are no longer fit to be used as bricks in construction. Odero, Mutuku and Kabubo (2015) observed that construction activities are both the primary consumer of bricks and source of brick waste. Odero et al (2015) further assert the need for construction to better use for burnt broken bricks rather than disposing such waste as land fill which is the common practice. Consequently, researches continue to experiment the performance of broken waste bricks when used as aggregate material in construction.

In the study area, a total of four researches were found on the performance of burnt brick as replacement of naturally occurring aggregate in construction. A search on google scholar of the phrase ‘’ Burnt bricks as aggregate in concrete’’ returned a total of 6,120 results. This shows that there is appreciable research output on the use of burnt bricks as aggregate in construction.

Researches, such as that of Odero et al (2015) who replaced coarse aggregate in percentages of 20,40,60, 80 and 100 with crushed burnt bricks reported 28 days compressive strength (N/mm^2) of 18,17,15,11, 11, and that of Kankal and Kariappa (2022) who also replaced naturally occurring coarse aggregate with crushed burnt bricks in percentages of 10,20,30 reported a 28days compressive strength (N/mm^2) of 31,22, 17 have shown the viability of using burnt bricks as aggregate in concrete production.

Crumb Rubber

Crumb Rubber (CR) is recycled waste rubber obtained from used vehicle tires, providing an environmentally friendly method of tire disposal (Hesami, Salehi, & Emadi, 2020). CR is produced through the process of crushing, grinding, separation, and screening of scrap tires. The accumulation of waste rubber tires in cities and towns globally makes scrap rubber a significant waste problem. In Northern Nigeria, waste rubber tires can be found in spare parts markets, along major roads as refuse, and in mechanic and vulcanization shops.

Several studies have demonstrated the feasibility of using CR as an aggregate material. Four research studies on the use of crumb rubber as a concrete aggregate material were conducted in the study area. Additionally, a Google Scholar search for "Crumb Rubber as concrete aggregate" yielded 3,360 results, indicating global research interest in this area.

Hesami et al. (2016) replaced naturally occurring aggregate with CR at percentages of 5%, 10%, and 15%, using a water-cement ratio of 0.39, and recorded 28-day compressive strengths (N/mm²) of 67, 60, and 55, respectively. Aslani and Asif (2020) conducted separate experiments where they replaced both fine and coarse aggregates with CR at percentages of 10% and 30%, and reported 28-day compressive strengths (N/mm²) of 27 and 27 when CR replaced fine aggregate, and 27 and 25 when CR was used as a partial replacement of coarse aggregate. These findings indicate that Crumb Rubber is a viable aggregate material that can replace both fine and coarse aggregate in concrete production.

Plastic Waste

Plastic waste materials, such as Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), and Polypropylene (PP), can also be used as aggregate materials in concrete production (Abu Saleem et al., 2021). Plastic waste, including waste plastic bottles, containers, components, and parts, is a prevalent urban pollutant globally (Belmokaddem et al., 2020). As a result, researchers have investigated the possibility of utilizing plastic waste as an aggregate material in concrete production. In the study area, four research studies were found on the use of plastic waste as a replacement for aggregate in concrete production. Additionally, a Google Scholar search for "Plastic waste as aggregate in concrete" yielded a total of 11,200 results, indicating significant research output in both the global and local contexts

Various researchers have conducted experiments on the use of plastic waste as aggregate materials in concrete production, with encouraging results. Belmokaddem et al. (2020) replaced fine aggregate at percentages of 25%, 50%, and 75% with waste PVC plastic and reported 28-day compressive strengths (N/mm²) of 26, 22, and 16, respectively. Similarly, Abu Saleem et al. (2021) replaced naturally occurring stone aggregate with HDPE plastic at percentages of 10%, 20%, and 30% and reported 28-day compressive strengths (N/mm²) of 25.7, 19.9, and 19.2. These findings indicate that various types of plastic waste can be utilized as aggregate materials to partially replace naturally occurring stone aggregate.

Burnt Bricks

Burnt bricks refer to broken or overburnt bricks that are no longer suitable for use in construction. Odero, Mutuku, and Kabubo (2015) observed that construction activities are both the primary consumers of bricks and a source of brick waste. They further emphasize the need to find better uses for burnt broken bricks rather than disposing of them as landfill, which is a common practice. Consequently, researchers have continued to investigate the performance of broken waste bricks when used as aggregate material in construction.

In the study area, four research studies were identified regarding the performance of burnt bricks as a replacement for naturally occurring aggregate in construction. A search on Google Scholar using the phrase "Burnt bricks as aggregate in concrete" yielded a total of 6,120 results, indicating a substantial amount of research output on the topic of using burnt bricks as aggregate in construction.

Research studies, such as that of Odero et al. (2015), replaced coarse aggregate at percentages of 20%, 40%, 60%, 80%, and 100% with crushed burnt bricks and reported 28-day compressive strengths (N/mm^2) of 18, 17, 15, 11, and 11, respectively. Another study conducted by Kankal and Kariappa (2022) replaced naturally occurring coarse aggregate with crushed burnt bricks at percentages of 10%, 20%, and 30% and reported 28-day compressive strengths (N/mm^2) of 31, 22, and 17. These findings demonstrate the viability of using burnt bricks as an aggregate in concrete production.

Broken Ceramics Tiles

Broken ceramic tiles are waste materials produced during the process of laying ceramic tiles in construction. Subedi, Wagle, and Basnet (2022) argue that a large volume of broken ceramic tiles becomes wastage that is not reusable or recyclable due to their physical and chemical structure. They emphasize that reusing waste tiles in the construction sector can reduce over-quarrying of naturally occurring aggregate and contribute to proper waste management in urban areas. As a result, there is a continued research interest in exploring the performance of broken ceramic tiles as aggregate material in concrete production.

Previous studies involving the use of broken ceramic tiles as aggregate in concrete showed encouraging results. For example, Subedi et al. (2020) and Adeala and Omisande (2021) employed the use of broken ceramic tiles as a replacement for coarse aggregates. These studies reported 28-day compressive strengths ranging from 20.9 N/mm^2 to 32 N/mm^2. Therefore, broken ceramic tiles present another viable material that can be used to replace naturally occurring aggregate in concrete.

Polystyrene

Polystyrene is one of the most common waste materials found in Nigerian towns, often appearing as waste water packaging bags and other forms of waste polythene packages. Kibria, Wahid, and Salam (2017) highlight that the safe disposal of post-consumer waste polymers, including polystyrene, has become a serious problem due to their large volume and non-biodegradable properties. They propose the use of polystyrene as an aggregate material in concrete production, leading to a growing research interest in this area.

Two research studies were found on the application of polystyrene as an aggregate material in construction. Additionally, a Google Scholar search using the phrase "polystyrene as aggregate in concrete" returned a total of 16,200 results, indicating that the use of polystyrene as aggregate in concrete is a well-researched topic globally.

Reviewing recent research on the use of polystyrene as an aggregate material in construction reveals promising results. For instance, Kibria et al. (2017) replaced coarse aggregates in concrete mixes with Expanded Polystyrene (EPS) at percentage ratios of 10%, 20%, 30%, and 40%, reporting 28-day compressive strengths (N/mm^2) of 20, 16, 14, and 12, respectively. Similarly, Gregrova and Unick (2016) replaced fine aggregates with EPS at percentage ratios of 25% and 75% and reported 28-day compressive strengths of 20 N/mm^2 and 17 N/mm^2.

Charcoal

Charcoal is another material that researchers have experimented with as a replacement for natural stone aggregate in concrete production, particularly in the production of lightweight concrete. It consists of the black granular remnants of burnt wood. The use of charcoal as an aggregate stems from the need to produce lightweight concrete using cheaper and readily available materials (Bikoko et al., 2019).

Here, two research studies were found that have explored the use of charcoal as an aggregate in construction. Furthermore, a Google Scholar search using the phrase "wood charcoal as aggregate in concrete" yielded a total of 14,900 results, indicating a significant research interest in using charcoal as an aggregate in construction.

Research on the use of charcoal as an aggregate primarily recommends its use in the production of lightweight concrete. For instance, Bikoko et al. (2019) replaced coarse aggregate with charcoal at percentage ratios of 25%, 50%, 75%, and 100% and reported 28-day compressive strengths (N/mm^2) of 9.92, 5.08, 2.87, and 2.48, respectively. The study concluded that the replacement of coarse aggregate with charcoal should not exceed 25%. Similarly, Pasalli, Pamuttu, Sepitipnon, and Hirulla (2021) replaced coarse aggregate with charcoal at percentage ratios of 25% and 50% and recorded 28-day compressive strengths of 8.3 N/mm^2 and 6.89 N/mm^2.

Lateritic Sandstone

Lateritic sandstone is a natural aggregate material derived from laterite soil. Asiedu (2017) describes it as an excellent source of all-in aggregate. Although it is not considered a waste material, Asiedu (2017) notes that it is a cost-effective alternative for constructing low-cost housing, as its extraction requires fewer resources compared to quarrying rocks.

In the study area, two research studies focused on the use of lateritic sandstone as an aggregate in construction. Furthermore, a Google Scholar search using the phrase "Lateritic sandstone as aggregate in concrete" returned a total of 12,200 results, indicating a significant research interest in the use of lateritic sandstone both locally and globally.

Asiedu (2017) conducted experiments on concrete production using lateritic sandstone as an all-in aggregate. Stone aggregate was replaced with lateritic sandstone at percentage ratios of 10%, 20%, and 30%, resulting in 28-day compressive strengths (N/mm^2) of 12.3, 13.9, and 16.3, respectively. Similarly, Marewangeng (2019) utilized lateritic sandstone as the sole fine aggregate in concrete mixtures and reported a 28-day compressive strength of 30.1 N/mm^2.

Other Alternative Aggregate Materials

Recycled aggregate, sawdust, date seeds, coconut shells, and crushed materials are other potential alternatives that can replace traditional stone aggregates. Each material was found in a single research study within the study area's library. However, a Google Scholar search for each of these alternative materials returned a minimum of 7,000 results, indicating their global recognition and experimentation as alternative aggregate materials.

These alternative materials in concrete production offer opportunities for sustainable construction practices, waste reduction, and resource conservation. Further research and exploration of their performance and applicability can contribute to the development of more environmentally friendly construction practices.
The result shows that there at least 14 different locally sourced materials which can adequately replace natural stone aggregate. The result also shows the materials can be used both as fine or

coarse aggregate. Other details of properties of identified alternative aggregates materials can be obtained from the authors.

CONCLUSION

This paper presents the results of a comprehensive survey conducted in physical libraries and virtual platforms, specifically Google Scholar, to identify locally available materials suitable as alternative aggregate materials to conventional naturally occurring rock aggregate. The study identified a total of 14 materials that have been investigated by researchers worldwide, demonstrating their potential to replace natural stone aggregate either partially or entirely, as either fine or coarse aggregate.

In conclusion, this study highlights the need to address the issues of over-dependence on and overexploitation of natural aggregate materials in concrete production. The identified local materials, as evidenced by previous research, offer promising alternatives that can contribute to sustainable construction practices and reduce the environmental impact associated with traditional aggregate extraction. By utilizing these local materials as aggregate substitutes, the construction industry can significantly reduce its reliance on natural resources and promote waste reduction.

Further research and experimentation are encouraged to explore the performance, durability, and long-term effects of incorporating these alternative materials into concrete mixtures. Additionally, considerations should be given to optimizing the production processes and developing appropriate guidelines and standards for incorporating these materials in concrete production. By embracing the use of alternative aggregate materials, the construction industry can contribute to a more sustainable and environmentally conscious approach to infrastructure development.

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