



## Investigating the impact of Silica Fume on the Engineering Properties of Concrete with Bama Gravel as the Coarse Aggregate

Shittu Nurudeen Jayeola, Yusuf Hadiza  
Civil Engineering Department,  
Ahmadu Bello University, Zaria

### ABSTRACT

Globally, concrete is the most widely used construction material. The composition of concrete plays an important role in controlling its overall performance. Concrete is composed of approximately 70%–80% aggregates, by volume. Therefore, it is mandatory to investigate the effect of aggregates on the performance of concrete. For this purpose, this experimental study investigates the impact of silica fume on the engineering properties of concrete incorporating Bama gravel as coarse aggregate. The research focuses on compressive strength, durability, and optimal silica fume dosage. Concrete mixes with varying silica fume proportions (0%, 5%, 10%, 15%, and 20%) were tested for compressive strength at 7, 14, and 28 days, and durability characteristics were assessed through slump and permeability tests. The results indicate significant improvements in compressive strength and durability with optimal silica fume addition (15%). Compressive strength increased by 7% at 28 days, while permeability reduced by 23%. However, excessive silica fume additions compromised these benefits. The study identifies 15% silica fume as the optimal dosage for balancing strength, durability, and workability. The findings contribute to the development of high-performance concrete mixes incorporating silica fume and Bama gravel, promoting sustainable construction practices.

### ARTICLE INFO

#### Article History

Received: Novem, 2024

Received in revised form: January, 2025

Accepted: March, 2025

Published online: June, 2025

### KEYWORDS

Concrete, Cement, Compressive Strength,  
Silica Fume, Bama Gravel and Durability

### INTRODUCTION

The construction industry is a cornerstone of economic development and infrastructure advancement, particularly in developing nations. As populations grow and urbanization intensifies, the demand for durable, cost-effective, and sustainable building materials has never been more critical [1]. In many parts of the world, including Nigeria, the availability and cost of construction materials significantly influence the feasibility and quality of building projects. This is especially true in the Northeastern states of Nigeria where the construction industry faces substantial challenges due to material shortages and high costs.

Concrete is the most widely used construction material globally due to its versatility, durability, and relatively low cost. The basic

components of concrete include cement, water, fine aggregates (sand), and coarse aggregates (gravel or crushed stone). The quality and properties of the coarse aggregate significantly influence the overall performance of concrete, including its strength, workability, and durability. Conventional gravel, typically sourced from riverbeds or quarries, is known for its optimal properties that contribute to high-quality concrete. According to [2], in some regions, the scarcity of this conventional gravel has necessitated the search for alternative materials. Bama gravel presents a significant drawback: the concrete produced with this material tends to have lower compressive strength compared to that made with conventional gravel. This limitation poses a considerable challenge in ensuring that structures

Corresponding author: Shittu Nurudeen Jayeola

✉ [shittunurudeen41@gmail.com](mailto:shittunurudeen41@gmail.com)

Civil Engineering Department, Ahmadu Bello University.

© 2025. Faculty of Technology Education. ATBU Bauchi. All rights reserved



built with Bama gravel concrete meet the required safety and performance standards [2].

Silica fume (SF) is a by-product of silicon material of industrial applications. It has become the most valuable by-product among the pozzolanic material due to its very active and pozzolanic property. Silica fume also known as micro-silica, is a by-product of the reduction of high purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. SF is also collected as a by-product in the production of other silicon alloys such as ferrochromium, ferromanganese, Ferro magnesium, and calcium silicon. The production process of these alloys results in the excess of amorphous silica content in SF. Before the mid-1970s, SF was discharged into the atmosphere. After environmental concerns necessitated the collection and landfilling of silica fume, it became economically justified to use silica fume in various applications such increasing compressive strength of concrete, improving bond strength, and abrasion resistance, reducing permeability, and therefore helps in protecting reinforcing steel from corrosion of concrete [3]

Cement production involves high energy consumption and its responsible for approximately 7% of the world's CO<sub>2</sub> emission. It is well known that CO<sub>2</sub> is a major contributor to the greenhouse effect and consequently responsible for global warming (Concrete Int 1999; 21). Therefore, research on use of by-product cementing materials, such as silica fume, volcanic ash, silica fumes and rice husk ash in place of cement has been increased in concrete technology [4].

Bama gravel, a locally available aggregate in Nigeria, has been identified as a suitable coarse aggregate for concrete production [5]. However, its use in combination with silica fume has not been extensively investigated. Bama gravel, a locally available aggregate in Nigeria, has been identified as a suitable coarse aggregate for concrete production [5] Aggregates are inert materials like sand, gravel, crushed stone, slag and recycled aggregates. The aggregates of a composite needs to be much smaller than the finished item and should come in a wide variety of

sizes for efficient filling. According to Portland cement association (2019), aggregates account for between 60 to 75% of the total volume of concrete, Aggregate is divided into two distinct categories, (fine aggregates less than 4.75mm in diameter and coarse aggregate greater than 4.75mm in diameter).

## LITERATURE REVIEW

Concrete remains the most widely used man-made construction material due to its availability, versatility, and cost-effectiveness. It is composed primarily of cement, water, fine aggregate (sand), and coarse aggregate (gravel or crushed stone), and its performance depends significantly on the quality and proportion of these constituents [6]. However, concrete production is increasingly scrutinized for its environmental impact. Cement manufacturing alone accounts for approximately 7% of global CO<sub>2</sub> emissions [7], driven by the high-energy demand and limestone calcination process. Furthermore, sourcing natural aggregates disrupts ecological systems and promotes environmental degradation [8].

Bama gravel, predominantly available in Northeastern Nigeria, is gaining attention as a potential substitute for conventional gravel due to its local abundance and economic viability. However, previous studies highlight its substandard mechanical performance, particularly lower compressive strength when used in concrete [9]. Since aggregate constitutes 70–80% of concrete volume, any deviation in its quality can significantly impact strength, durability, and workability [10]. The challenge thus lies in improving the mechanical behavior of Bama gravel concrete to meet structural requirements. Silica fume, a byproduct of silicon and ferrosilicon alloy production, is composed of ultrafine amorphous silica particles [11]. With a surface area ranging from 15,000–30,000 m<sup>2</sup>/kg and particle size approximately 0.1–0.2 µm, silica fume enhances concrete's microstructure by filling voids and participating in pozzolanic reactions with calcium hydroxide to form additional calcium silicate hydrate (C-S-H), thereby increasing strength and impermeability [12].

It has been shown to reduce permeability by 30–50% and increase compressive strength significantly, especially at later ages [13]. However, dosage is critical — while 10–15% silica fume replacement generally improves concrete properties, excess usage (above 20%) may result in poor workability and microcracking due to increased water demand and high heat of hydration [14].

## MATERIALS AND METHODOLOGY

### Materials

The Portland limestone cement (PLC) used was Dangote BlocMaster grade 42.5R, having a moisture content of 1.81% and specific gravity of 3.16. The fine aggregate used was sourced from Zaria Local Government Area, Kaduna State, Nigeria with a specific gravity of 2.50. The coarse aggregate used has a specific gravity of 2.65 and a bulk density of 1520 kg/m<sup>3</sup>. The Bama gravel was obtained from Borno State, Nigeria, with a specific gravity of 2.67. The silica fume was sourced from Zaria Local Government Area, Kaduna State, Nigeria. The water used was sourced from the Department of Civil Engineering Laboratory of ABU, Zaria, Kaduna State, Nigeria.

### Methods

The workability test was performed on fresh concrete with accordance to BS 1881:102 (1983). The compressive strength test on the silica fume and bama gravel concrete was conducted in line with BS EN 12390-3 (2019) with a total of 45 cubes were cast using varying percentages of silica fume to replace cement with a W/C ratio of 0.5. The cubes were tested each for 7, 14, and 28 days after curing. Three cubes were each tested for each percentage replacement of silica fume for 7, 14 and 28 days after curing.

## RESULTS AND DISCUSSIONS

### Slump Test of Silica Fume Concrete

The slump test results presented in Figure 1, reveal varying workability trends with increasing silica fume admixture proportions in Bama gravel concrete. Initially, workability decreases with 5% and 10% silica fume additions, indicated by reduced slump values (45mm and 35mm, respectively), suggesting increased paste

viscosity. However, a notable improvement in workability occurs at 15% silica fume, with a slump value of 65mm, indicating optimal paste-aggregate interactions. Further increase to 20% silica fume results in a slight reduction in workability (55mm), potentially due to over-addition of silica fume. These findings highlight the importance of precise silica fume proportioning to achieve desired workability and flowability in Bama gravel concrete, with 15% emerging as the optimal admixture ratio for enhanced workability.

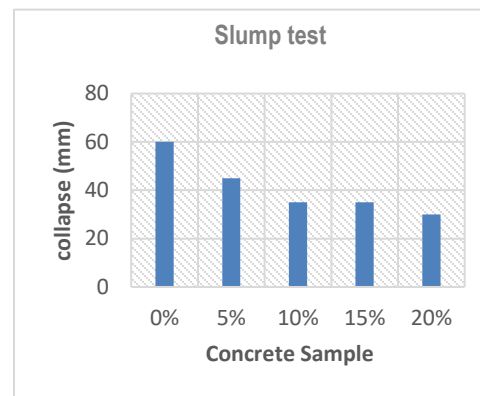


Figure 1: Slump test results

### Compressive Strength of Silica Fume Concrete

The compressive strength test results presented in Figure 2, reveal significant variations in concrete's strength with differing silica fume admixture proportions and curing durations. The control sample (0% silica fume) exhibits consistent strength gains throughout the curing periods, achieving 17.33 N/mm<sup>2</sup> at 7 days, 18.67 N/mm<sup>2</sup> at 14 days, and 22.67 N/mm<sup>2</sup> at 28 days. Conversely, incorporating silica fume leads to initial strength reductions. The 5% and 10% silica fume admixtures show lower strengths at 7 and 14 days, indicating potential delays in hydration. However, the 15% and 20% silica fume admixtures demonstrate improved strengths at 28 days.

At 28 days, the 15% silica fume admixture surpasses the control sample's strength, achieving 24.2 N/mm<sup>2</sup>. This suggests that optimal silica fume proportions can enhance

concrete's long-term strength. In contrast, lower silica fume proportions (5% and 10%) result in reduced strengths, highlighting the importance of precise admixture ratios. The 20% silica fume admixture also shows improved strength at 28 days, although slightly lower than the 15% admixture. These results indicate that silica fume's influence on strength is highly dependent on admixture proportions.

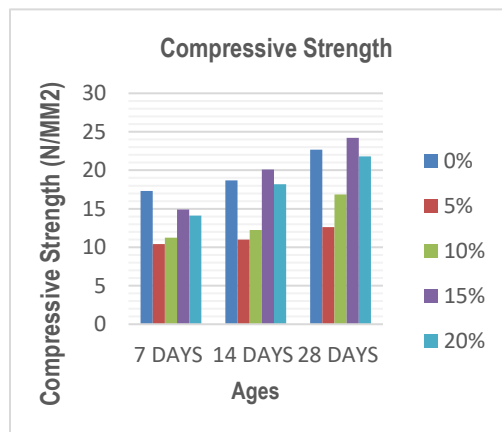


Figure 2: Compressive strength results

## CONCLUSION

The incorporation of silica fume significantly enhances the compressive strength of concrete with Bama gravel as coarse aggregate. The optimal replacement ratio of 15% silica fume yields the highest compressive strength. However, excessive silica fume additions compromise strength.

Silica fume improves the durability characteristics of concrete with Bama gravel as coarse aggregate. The results indicate reduced permeability and increased resistance to degradation. This enhancement is attributed to silica fume's pozzolanic reactions.

The study identifies 15% silica fume as the optimal dosage for improving the engineering properties of concrete with Bama gravel. This proportion balances strength, durability, and workability. Exceeding this dosage may compromise these benefits.

## RECOMMENDATIONS

1. The use 15% silica fume admixture for enhanced compressive strength. Avoid excessive silica fume additions to prevent strength loss.
2. The incorporate silica fume to improve durability characteristics. Optimize silica fume proportions to balance durability and strength.
3. The Adoption 15% silica fume as the standard dosage for Bama gravel concrete is recommended
4. Further research is recommended to investigate the long-term durability, microstructural properties, and environmental impacts of silica fume-modified Bama gravel concrete, as well as its tensile strength, shrinkage, and creep behavior under various exposure conditions

## REFERENCES

- [1] Ofori, G. (2015). Nature of the construction industry, its needs and its development: A review of four decades of research. *Journal of Construction in Developing Countries*, 20(2), 115–135.
- [2] Olusola, K. O. (2021). Exploring alternative coarse aggregates in Nigerian construction. *Journal of Civil Engineering and Construction Technology*, 12(1), 12–20.
- [3] Anwar, M., & Hussein, M. (2023, March). Effect of using silica fume on concrete performance against sulfate attack. In *Proceedings of the International Conference on Advances in Structural and Geotechnical Engineering (ICASGE'23)* (Hurghada, Egypt)
- [4] Shetty, M. S. (2005). *Concrete Technology: Theory and Practice* (Multi-Colour Illustrated ed.). S. Chand Publishing.
- [5] Okafor, F. O. (2017). Performance of concrete using Bama gravel as coarse aggregate. *Nigerian Journal of Engineering Research*, 5(2), 15–20.



- [6] Neville, A. M. (1995). Properties of Concrete, Fourth Edition. England: Longman Group Limited.
- [7] Meyer, C. (2009). The greening of the concrete industry. Cement and Concrete Composites, 31(8), 601–605.
- [8] Sairanen, M., Rinne, M., & Selonen, O. (2018). A review of dust emission dispersions in rock aggregate quarries. International Journal of Mining, Reclamation and Environment, 32(3), 196–220.
- [9] Olusola, K. O. (2021). Exploring alternative coarse aggregates in Nigerian construction. Journal of Civil Engineering and Construction Technology, 12(1), 12–20.
- [10] Ahmad, S.; Alghamdi, S.A. A study on effect of coarse aggregate type on concrete performance. Arab. J. Sci. Eng. 2012, 37, 1777–1786. [CrossRef]
- [11] Mazloom, M.; Ramezani pour, A.; Brooks, J. Effect of silica fume on mechanical properties of high-strength concrete. Cem. Concr. Compos. 2004, 26, 347–357. [CrossRef]
- [12] Siddique, R. (2011). Utilization of silica fume in concrete: Review of hardened properties. Resources, Conservation and Recycling, 55(11), 923–932.
- [13] Khodabakhshian, A.; Ghalehnovi, M.; De Brito, J.; Shamsabadi, E.A. Durability performance of structural concrete containing silica fume and marble industry waste powder. J. Clean. Prod. 2018, 170, 42–60. [CrossRef]
- [14] Beshr, H., Almusallam, A., & Maslehuddin, M. (2003). Effect of coarse aggregate quality on the mechanical properties of high-strength concrete. Construction and Building Materials, 17, 97–103.