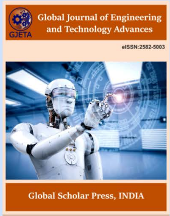
Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/



(Research Article)

Mechanical Performance of M25 concrete incorporating basalt and limestone as coarse aggregate replacements

Mona Adam Gumma Rabih, Ammar Babiker * and Eltahir Abuelgasim Mohamed Elshaikh

School of Civil Engineering, College of Engineering, Sudan University of Science and Technology, P.O. Box 72, Eastern Daim, Khartoum, Sudan.

Global Journal of Engineering and Technology Advances, 2026, 26(03), 232-243

Publication history: Received on 17 February 2026; revised on 23 March 2026; accepted on 26 March 2026

Article DOI: https://doi.org/10.30574/gjeta.2026.26.3.0071

Abstract

This study systematically evaluates the influence of progressively replacing natural coarse aggregates with basalt, supplemented by a limited proportion of limestone, across a range of substitution levels. A comprehensive analysis of mechanical performance demonstrates that the mixture composed entirely of basalt achieves the highest strength and overall structural efficiency, while the hybrid composition containing 75% basalt and 25% limestone also delivers notably strong performance. These findings underscore the superior mechanical characteristics of basalt relative to conventional aggregates and confirm its suitability for demanding structural concrete applications. In addition to quantifying strength improvements, the results provide deeper insight into the synergistic behavior between basalt and limestone within the concrete matrix, particularly in terms of load transfer mechanisms, particle interlocking, and overall matrix densification. This enhanced understanding contributes to the broader body of knowledge on aggregate optimization in concrete technology. From a practical perspective, the study offers valuable guidance for engineers and practitioners by identifying optimal mixture proportions that balance performance and material efficiency. Furthermore, the adoption of basalt, especially when locally available, presents a viable pathway toward producing stronger, more durable, and environmentally sustainable concrete, thereby supporting ongoing efforts to reduce the environmental footprint of construction materials.

Keywords: Basalt; Limestone; Workability; Natural Aggregate; Compressive Strength; Concrete**.**

1. Introduction

Concrete remains the cornerstone of modern construction due to its exceptional versatility, durability, and capacity to incorporate locally available materials. Its widespread application in infrastructure systems from buildings and bridges to pavements and hydraulic structures stems from its ability to be tailored to a wide range of mechanical and environmental requirements. Among its primary constituents, coarse aggregates account for approximately 70–75% of the total concrete volume, rendering their physical characteristics, mineralogical composition, and mechanical properties critical determinants of overall concrete performance. Consequently, considerable research efforts have been devoted to exploring alternative aggregate materials that can simultaneously enhance structural performance and contribute to more sustainable construction practices [1–3]. Traditionally, natural gravel has served as the predominant source of coarse aggregate in many regions. However, escalating demand for construction materials, coupled with increasing environmental concerns related to resource depletion and ecological degradation, has prompted a shift toward the investigation of alternative aggregate sources. Igneous rocks such as basalt, granite, and gabbro have emerged as promising candidates due to their inherently superior engineering properties. These materials typically exhibit higher density, lower porosity, and greater resistance to mechanical stresses compared with conventional sedimentary aggregates. As a result, their incorporation into concrete mixtures has been associated with significant

* Corresponding author: Ammar Babiker.

improvements in compressive strength, durability, and resistance to wear and environmental attack [4,5]. A growing body of literature has emphasized the critical role of aggregate mineralogy in influencing the behavior of concrete. Basalt, in particular, has attracted considerable attention due to its high hardness and favorable bonding characteristics with cement paste. Previous studies have demonstrated that basalt aggregates can enhance both compressive and tensile strengths, primarily through improved interfacial transition zone (ITZ) properties and enhanced load transfer mechanisms. Similarly, comparative investigations have shown that basalt-based concrete often outperforms granite-based concrete in terms of abrasion resistance and overall structural performance, highlighting its suitability for demanding engineering applications[6,7].

In addition to mechanical advantages, basalt aggregates have been increasingly recognized for their contribution to the durability and sustainability of concrete. Their low absorption and dense microstructure reduce permeability, thereby limiting the ingress of harmful agents such as chlorides and sulfates. This improved resistance to aggressive environments enhances the long-term performance and service life of concrete structures. Furthermore, the use of basalt aggregates has been linked to reduced maintenance requirements, offering economic as well as environmental benefits over the lifecycle of infrastructure systems [5,8]. Recent research has expanded beyond conventional aggregate replacement to explore the utilization of igneous byproducts and hybrid material systems. For instance, the incorporation of gabbro stone powder as a partial substitute for cement has demonstrated promising results, particularly at moderate replacement levels (5–10%). Such mixtures have been shown to achieve enhanced compressive strength while simultaneously reducing the heat of hydration, thereby mitigating thermal cracking in mass concrete applications. These findings underscore the potential of gabbro-derived materials in the development of low-carbon, sustainable concrete technologies [9,10]. Similarly, studies examining the combined use of basalt aggregates and mineral admixtures under sulfate exposure conditions have revealed significant improvements in both mechanical performance and chemical durability, indicating their suitability for use in aggressive service environments [11].

Parallel to these developments, renewed attention has been directed toward the integration of limestone within blended aggregate systems. Optimized combinations of basalt and limestone have been shown to achieve a balance between strength, workability, and cost-effectiveness. The inclusion of finely ground basalt powder as a supplementary cementitious material further enhances microstructural refinement, particularly within the ITZ, leading to improved mechanical properties and rheological behavior. These enhancements are especially beneficial in environments characterized by chemical exposure, such as saline or sulfate-rich conditions, where durability is of paramount importance [12]. Despite these advances, there remains a notable gap in the literature concerning the combined use of gabbro and granite aggregates, particularly in medium-strength concrete grades such as M25. While individual studies have examined the performance of these materials in isolation, limited research has addressed their synergistic effects when used together in varying proportions. Understanding how these aggregates interact within the concrete matrix and how they influence both fresh properties, such as workability, and hardened properties, such as strength development is essential for optimizing mix design. Moreover, such investigations are crucial for promoting the efficient use of locally available materials, thereby reducing transportation costs and associated environmental impacts [13]. In light of these considerations, the present study aims to systematically evaluate the performance of M25 grade concrete incorporating different proportions of gabbro and granite as coarse aggregates. The research focuses on key performance indicators, including workability and compressive strength at curing ages of 7, 28, and 56 days. By providing a detailed assessment of how aggregate composition influences both early-age and long-term behavior, this study seeks to contribute to the development of optimized, sustainable concrete mixtures. Ultimately, the findings are expected to offer practical guidance for engineers and practitioners in designing high-performance concrete systems that effectively utilize locally sourced aggregate materials while meeting the demands of modern construction.

2. Research methodology

2.1. Materials

To achieve the aims of this investigation, a comprehensive experimental program was designed and executed utilizing materials sourced locally from Khartoum State. The subsequent sections provide a detailed account of the constituent materials as well as the methodologies adopted for testing and evaluation. Rigorous material characterization is essential for accurately assessing the behavior and performance of concrete mixtures; therefore, each selected test was carefully chosen to generate reliable and meaningful data. The rationale underlying the inclusion of these tests is discussed to clarify their relevance in validating the study’s objectives and ensuring the robustness of the experimental findings.

2.1.1. Cement

Type I Ordinary Portland Cement (OPC), obtained from the Berber Cement Plant, was employed as the primary binder in this investigation. Key physical properties including fineness, standard consistency, and both initial and final setting times were measured in accordance with the procedures specified in BS 12:1996–2003 [14], and the corresponding results are summarized in Table 1. These parameters play a fundamental role in assessing the suitability and performance of cement in concrete applications. In particular, fineness is a critical factor influencing hydration kinetics, as an increased specific surface area promotes faster chemical reactions and contributes to improved early-age strength development [15,16]. Meanwhile, standard consistency and setting time are essential indicators of the cement's workability and hardening behavior, ensuring that the material maintains adequate plasticity during placement while avoiding undesirable premature setting, especially in large-scale construction operations.

Table 1 Result of cement test

Test	Result	Standard range according to BS 12:1996–2003 [14]
Fineness (%)	1.5	not more than 10%
Consistency (%)	30	26% — 33%
Initial Setting Time (min)	52	not less than 45 min
Final Setting Time (hrs)	6.5	not more than10 hours
Soundness (mm)	2.0	less than 10 mm
Compressive strength at 3 days [MPa]	19.8	Grater than or equal to 10 MPa
Compressive strength at 28 days [MPa]	46.5	Grater than or equal to 42.5 MPa

2.1.2. Water

Clean potable water sourced from the River Nile was utilized in this study. Water plays a fundamental role in concrete production, as it actively participates in the hydration process of cement, leading to the formation of cementitious gel that governs strength development. Consequently, both the quality and precise quantity of mixing water must be carefully controlled and thoroughly evaluated to ensure optimal mechanical performance and durability of the resulting concrete.

2.1.3. Fine aggregate

Fine aggregate utilized in this study was sourced from the Algitaina area in White Nile State and subjected to a series of preparatory treatments to ensure its suitability for concrete production. The material was thoroughly washed to remove impurities, oven-dried to eliminate moisture content, and subsequently sieved to achieve the required grading profile. Particle size distribution was determined through standard sieve analysis using apertures of 4.75 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and 75 µm, along with a receiving pan, with the results presented in Table 2. The gradation curve derived from this analysis, illustrated in Figure 1, complies with the procedures outlined in BS EN 933-2:2020 [17].

Figure 1 presents the particle size distribution curves of both fine aggregate (FA) and natural coarse aggregate (NA), providing a comparative assessment of their grading characteristics. As illustrated, the FA curve exhibits a smooth and continuous distribution across the finer sieve sizes, indicating a well-graded sand with an adequate proportion of particles spanning from coarse to fine fractions. This uniform gradation is essential for achieving improved packing density, which in turn enhances the workability and cohesiveness of the fresh concrete mixture. In contrast, the NA curve is shifted toward the coarser particle range, with a steeper slope, suggesting a relatively narrower gradation and a predominance of larger particle sizes.

The distinction between the two curves highlights the complementary roles of FA and NA in the concrete matrix. The finer particles of the FA effectively fill the voids between the coarser NA particles, reducing porosity and contributing to a denser and more compact microstructure. This interaction is particularly important for optimizing the interfacial transition zone (ITZ), which significantly influences the mechanical performance and durability of hardened concrete. Moreover, the gradation trends observed in Figure 1 demonstrate compliance with standard specifications, ensuring that both aggregates meet the necessary criteria for structural applications.

Overall, the results depicted in Figure 1 confirm that the selected aggregates possess suitable grading characteristics for concrete production. The well-graded nature of the FA, combined with the coarse fraction of the NA, is expected to promote efficient particle packing, reduce void content, and ultimately enhance the strength and durability properties of the resulting concrete.

In addition to gradation, key physical properties of the FA were evaluated to ensure its adequacy for structural applications. The FA exhibited a specific gravity of 2.59 and a water absorption capacity of 0.88%, as detailed in Table 3. These parameters are critical indicators of aggregate quality, influencing both the workability of fresh concrete and the durability of the hardened matrix. Rigorous characterization of the fine aggregate is therefore essential not only for verifying compliance with established British Standards but also for ensuring consistency, reproducibility, and reliable mechanical performance in the final concrete product [17] .

2.1.4. Natural coarse aggregates

Three distinct types of coarse aggregates were incorporated in this investigation: naturally uncrushed aggregate (NA) sourced from western Omdurman, crushed basalt (BA) obtained from Turia Mountain in Omdurman, and crushed limestone (LA) collected from the same location (see Table 2). The particle size distribution of the natural aggregate, determined through sieve analysis, is presented in Figure 1 and conforms to the procedures specified in BS EN 933-2:2020 [17].

Table 2 Fine and coarse aggregate gradation**.**

Aggregates type	**Sieve size (mm)**	**Weight retained (gm)**	**Cumulative weight retained (gm)**	**Percentage of cumulative retained (%)**	**Percentage of cumulative passing (%)**
Natural coarse aggregates (NA)	19	209	209	10.45	89.55
	12.5	331	540	27.00	73.00
	9.5	876	1416	70.80	29.20
	4.75	479	1895	94.75	5.250
	Pan	105	2000	100	0.0
Fine aggregates (FA)	4.75	–	0.0	0.0	100
	2.36	337	337	16.85	83.15
	1.18	320	657	32.85	67.15
	0.6	473	1130	56.5	43.4
	0.3	242	1372	68.6	31.4
	0.15	182	1554	77.7	22.3
	0.075	302	1856	92.8	7.2
	Pan	144	2000	100	0.0

All aggregates were characterized for specific gravity (SG), moisture content (MC), and water absorption (WA) in accordance with BS 1996–2003 [14]. The results are presented in Table 3, while photographs of the materials are shown in Figure 2. These tests are essential for assessing aggregate quality and suitability [17].

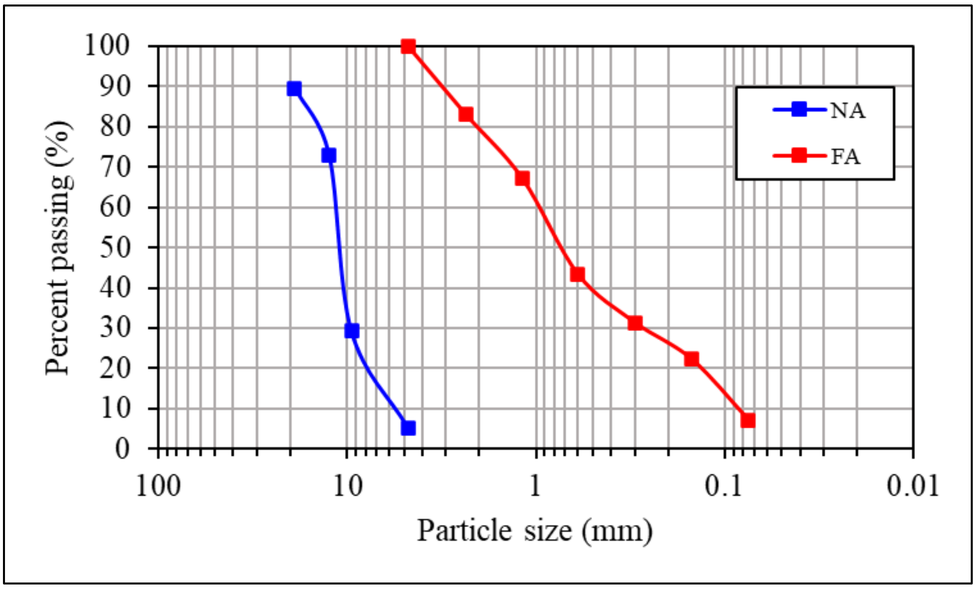


Figure 1 Grading of FA and NA aggregates

Table 3 Results of materials tests.

Test	**Result**				**Standard range according to 1996–2003 [14]**
	FA	NA	BA	LA	
SG (–)	2.59	2.68	2.88	2.63	Minimum 2.6
MC (%)	0.40	0.40	0.32	0.36	Maximum 2%
WA (%)	0.88	0.70	0.65	0.9	Maximum 2%

Figure 2 Materials used to produce M25 grade concrete**.**

2.2. Experimental program

2.2.1. Mix design and specimens preparation

Concrete mixtures were designed in accordance with the British Standard method to attain a target characteristic compressive strength of 25 MPa (M25 grade). A total of six distinct mix compositions were developed, as detailed in Table 4. The reference mixture (NA100BA0LA0) utilized 100% natural, uncrushed coarse aggregate. The remaining mixtures were formulated by varying the proportions of BA and LA. Specifically, NA0BA100LA0 comprised entirely basalt, NA0BA75LA25 included 75% basalt and 25% limestone, NA0BA50LA50 incorporated equal proportions of both aggregates, NA0BA25LA75 contained 25% basalt and 75% limestone, and NA0BA0LA100 consisted exclusively of limestone. To ensure a controlled comparison, all mixtures were prepared with a constant water-to-cement ratio and identical fine aggregate content, thereby isolating the influence of coarse aggregate composition on concrete performance. For each mix, nine cube specimens with dimensions of 150 × 150 × 150 mm were cast (Figure 3). After casting, the specimens were demolded at 24 hours and subsequently cured in water for periods of 7, 28, and 56 days to monitor strength development over time. The workability of the fresh concrete was assessed using the slump test in accordance with standard testing procedures, while compressive strength was determined at each curing age using a calibrated compression testing machine. This experimental approach ensured reliable and consistent evaluation of the mechanical behavior of all concrete mixtures.

Figure 3 M25 cube specimens.

Table 4 Designation of M25 concrete mixes.

Concrete mix	Percentage of course aggregates (NA%:BA%:LA%)
NA100BA0LA0	100%: 0.0%: 0.0%
NA0BA100LA0	0.0%: 100%: 0.0%
NA0BA75LA25	0.0%: 75%: 25%
NA0BA50LA50	0.0%: 50%: 50%
NA0BA25LA75	0.0%: 25%: 75%
NA0BA0LA100	0.0%: 0.0%: 100%

3. Results and discussion

This section presents and interprets the findings obtained from the experimental program. The behavior of the six concrete mixtures was assessed using two primary performance indicators: workability, determined through the slump test, and compressive strength measured at curing ages of 7, 28, and 56 days.

3.1. Slump test result

The workability of the fresh concrete mixtures was evaluated using the slump test (Figure 3), and the corresponding results for all mix proportions are presented in Figure 4. As shown in Figure 4, the slump values for the control and basalt-rich mixtures (NA100BA0LA0, NA0BA100LA0, and NA0BA75LA25) remained consistently high at 60 mm, indicating comparable levels of workability. However, a gradual reduction in slump is observed with increasing limestone content, where the values decrease to 58 mm, 55 mm, and ultimately 45 mm for the NA0BA50LA50, NA0BA25LA75, and NA0BA0LA100 mixes, respectively. This trend suggests that mixtures with higher basalt content maintain superior workability, while increasing the proportion of limestone adversely affects flowability. The relatively stable slump values in basalt-dominant mixes can be attributed to the lower water absorption and smoother surface texture of basalt particles, which facilitate better lubrication within the mix. In contrast, the decline in workability with higher limestone content is likely due to its comparatively rougher surface texture and higher absorption, which reduce the amount of free water available for flow. Overall, the results presented in Figure 4 highlight the significant influence of aggregate type and composition on the rheological behavior of fresh concrete. The incorporation of basalt aggregate contributes to maintaining higher workability, whereas increasing limestone content leads to a noticeable reduction in slump. These findings emphasize the importance of optimizing aggregate proportions to achieve the desired balance between workability and other performance characteristics in concrete mix design.

Figure 4 Temperature control and slump test configuration.

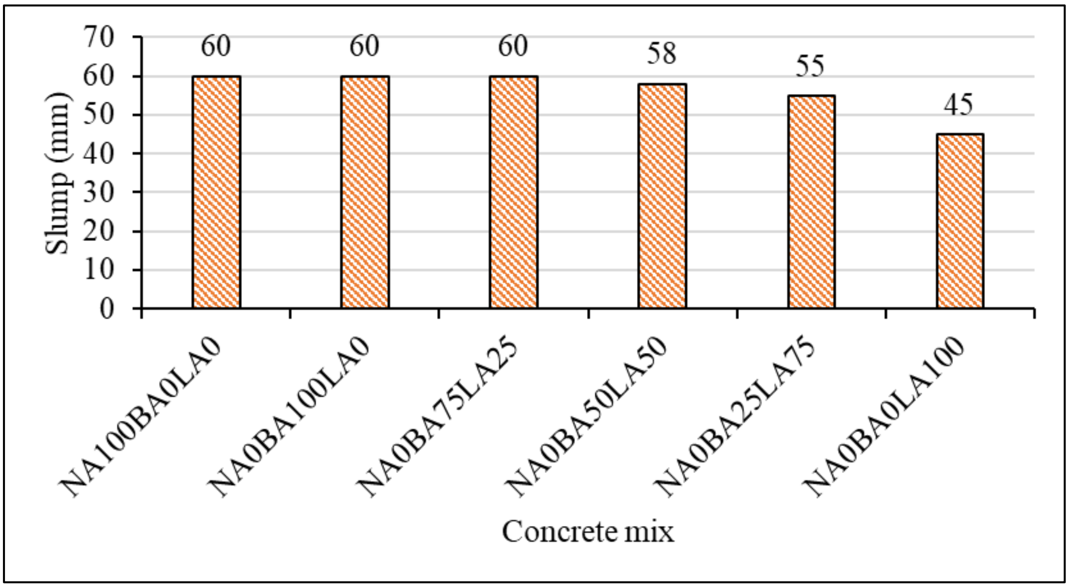


Figure 5 Slump workability of M25 concrete mixes**.**

3.2. Compressive strength test results

The compressive strength results obtained in the present study (Table 5 and Figure 6) demonstrate clear and consistent trends across all curing ages, highlighting the significant influence of aggregate composition on the mechanical performance of M25 concrete. The mixture incorporating 100% basalt (NA0BA100LA0) exhibited the highest strength values at all testing ages, achieving 29.8 MPa, 34.6 MPa, and 42.5 MPa at 7, 28, and 56 days, respectively. In comparison, the control mix containing 100% natural aggregate (NA100BA0LA0) recorded lower strengths of 23.5 MPa, 31.2 MPa, and 37.0 MPa at the corresponding ages. These results indicate strength enhancements of approximately 26.8%, 10.9%, and 14.9% at 7, 28, and 56 days, respectively, thereby confirming the mechanical superiority of basalt aggregates. Mixtures incorporating combined proportions of basalt and limestone exhibited intermediate performance, with compressive strength gradually decreasing as the limestone content increased. For example, the NA0BA75LA25 mix achieved strengths of 27.3 MPa, 33.5 MPa, and 41.0 MPa at 7, 28, and 56 days, respectively, maintaining performance levels close to those of the fully basaltic mix. However, further increases in limestone content led to a noticeable reduction in strength, as observed in the NA0BA50LA50, NA0BA25LA75, and NA0BA0LA100 mixes. The latter, consisting entirely of limestone aggregate, exhibited the lowest strengths of 24.3 MPa, 29.0 MPa, and 33.7 MPa at the respective curing ages. The observed strength enhancement with increasing basalt content can be attributed to its high density, low porosity, and reduced water absorption, which collectively improve the interfacial bond between the aggregate and cement paste. This results in a denser and more homogeneous microstructure with fewer voids, thereby enhancing load transfer efficiency. Conversely, the reduced performance of limestone-rich mixtures may be associated with comparatively higher water absorption and weaker aggregate–paste interaction. These findings are in strong agreement with previously reported studies, further reinforcing the effectiveness of basalt as a high-performance coarse aggregate.

Table 5 Compressive strength of M25 concrete at various ages.

Concrete mix	Compressive strength (MPa)		
	7 days	28 days	56 days
NA100BA0LA0	23.5	31.2	37.0
NA0BA100LA0	29.8	34.6	42.5
NA0BA75LA25	27.3	33.5	41.0
NA0BA50LA50	26.7	32.5	39.0
NA0BA25LA75	25.5	30.6	36.0
NA0BA0LA100	24.3	29	33.7

Previous research has documented compressive strength increases of up to 62%, with values rising from 35.1 MPa for conventional concrete to 56.8 MPa for basalt-based mixtures, alongside substantial improvements in flexural strength exceeding 220% [9,18]. Similarly, the incorporation of waste basalt at a replacement level of 75% has been shown to increase compressive strength from 40.2 MPa to 51.8 MPa [1,19]. In high-strength concrete applications, basalt aggregates have demonstrated exceptional potential, with compressive strengths approaching 200 MPa under optimized conditions, primarily due to their superior intrinsic strength and favorable surface characteristics [5,18]. Overall, the results of the present study corroborate existing literature and confirm that basalt is a highly effective coarse aggregate for enhancing the mechanical performance and durability of concrete. At the same time, partial replacement with limestone offers a viable approach for optimizing material usage while maintaining acceptable strength levels, thereby supporting the development of more sustainable and efficient concrete mixtures.

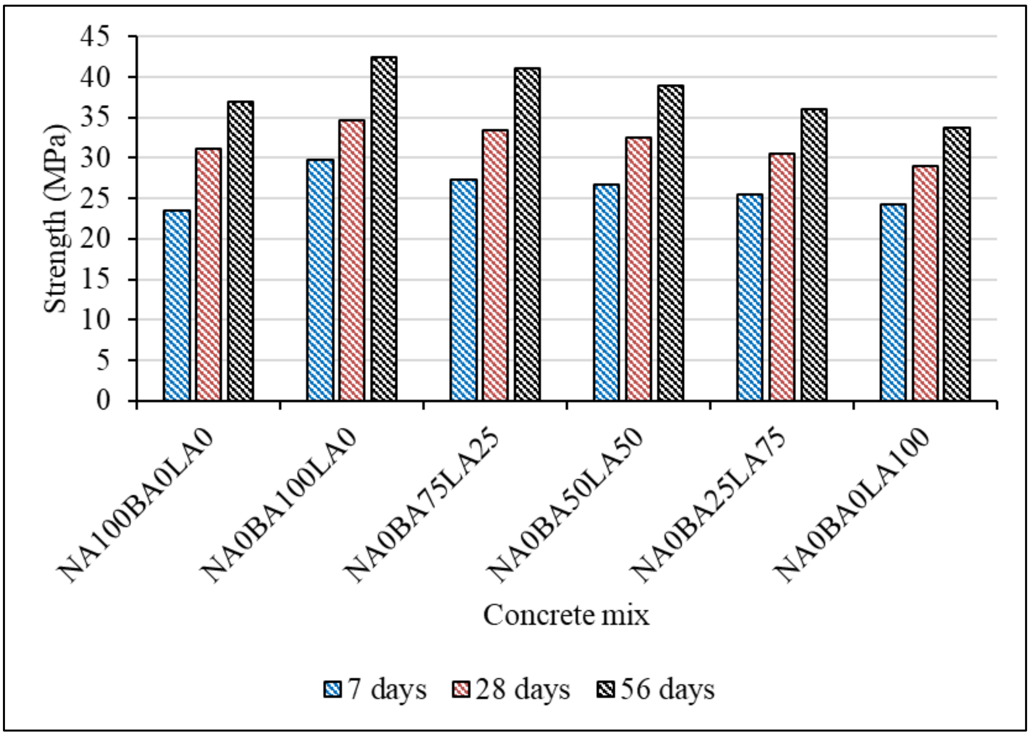


Figure 6 Compressive strength of M25 concrete at different ages

3.3. Failure modes

The failure pattern of cube specimens was examined (Figure 7). The images illustrate distinct cracking and spalling behaviors among different mix compositions, indicating varying responses under compressive loading. Specimens with a higher proportion of natural aggregates (such as NA100BA0LA0 and NA0BA100LA0) demonstrated more brittle failure characterized by explosive cracking and visible disintegration of aggregate particles. This suggests a relatively stiff and less ductile matrix where the applied stress exceeded the cohesive strength abruptly, leading to catastrophic failure. In contrast, mixes incorporating lightweight aggregates (e.g., NA0BA75LA25, NA0BA50LA50, NA0BA25LA75, and NA0BA0LA100) displayed more gradual and distributed cracking patterns. These specimens exhibited vertical and diagonal cracks with limited spalling, indicating a more ductile failure mode and enhanced energy absorption capacity. The progressive widening of cracks in these samples implies better strain accommodation before ultimate failure, likely due to the lower stiffness and higher porosity of lightweight aggregates, which allow for greater deformation under stress.

Figure 7 Failure modes of cube specimens

3.4. Statistical analysis

A probability plot was generated to evaluate the normality of the compressive strength data. This framework was crafted utilizing the preceding experimental data from Table 5 harnessed the capabilities of a versatile statistical software program [Minitab [20] (version 19.0)].

As illustrated in Figure 8, the plotted data points closely follow the reference line and remain well within the 95% confidence intervals, indicating a satisfactory agreement with the normal distribution. The dataset is characterized by a mean value of 32.09 MPa and a standard deviation of 5.603, reflecting a moderate dispersion around the central tendency. Statistical validation further supports this observation, as the obtained p-value of 0.970 is substantially higher than the commonly accepted significance level ($\alpha = 0.05$), thereby confirming the absence of any statistically significant departure from normality. In addition, the relatively low Anderson–Darling statistic reinforces the suitability of the normality assumption. The strength of the relationship between the observed data and the corresponding theoretical normal quantiles is evidenced by a high correlation coefficient ($R = 0.90$), indicating a strong linear association. Collectively, these results confirm that the compressive strength data are well approximated by a normal distribution, thereby justifying the application of parametric statistical techniques in subsequent analyses.

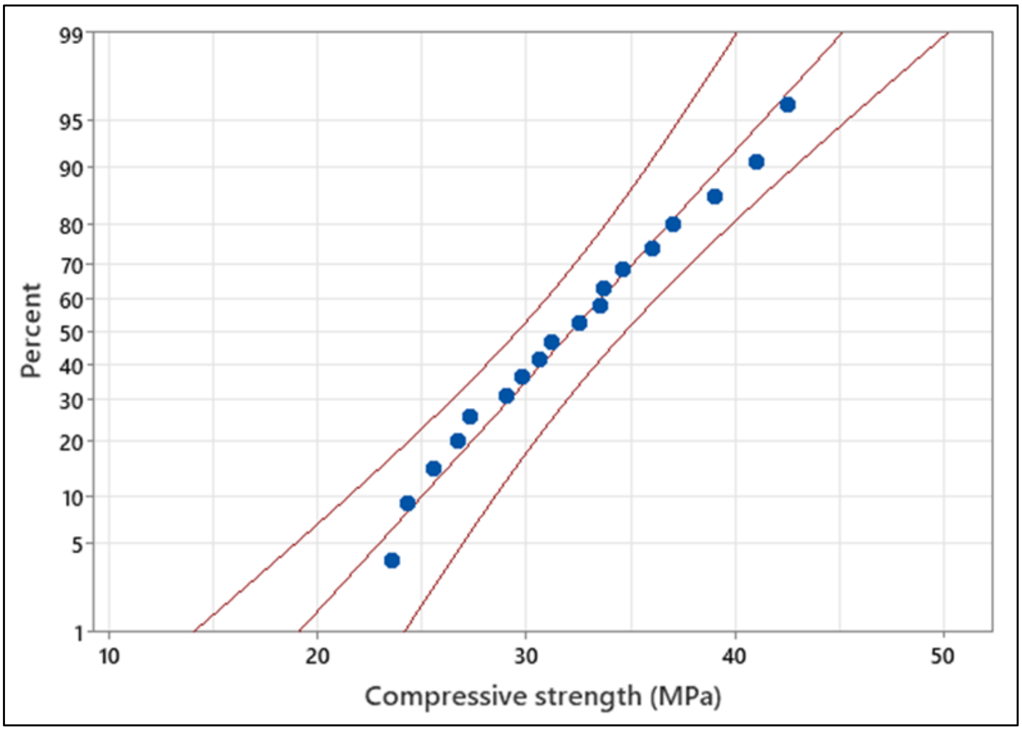


Figure 8 A probability plot of compressive strength

3.5. Novelty in comparison with related research

This study advances existing research by providing a systematic and context-specific evaluation of basalt–limestone aggregate systems within Sudan, addressing a notable gap in the literature on regionally available construction materials. In contrast to prior studies that typically assess aggregate types independently, the present work adopts an integrated approach by examining the combined effects of basalt and limestone across multiple replacement levels, thereby capturing their interactive influence on concrete performance. This holistic framework enables a more realistic representation of practical mix design scenarios, particularly in regions where material blending is common due to resource availability constraints. A key contribution of this research lies in its dual focus on both fresh and hardened concrete properties, linking workability characteristics with strength development over curing periods of 7, 28, and 56 days. This comprehensive evaluation provides deeper insight into the relationship between aggregate composition, rheological behavior, and long-term mechanical performance. Furthermore, the study extends beyond conventional strength assessment by elucidating the underlying mechanisms governing performance enhancement, including improved particle packing, interfacial bonding, and matrix densification associated with basalt incorporation. Methodologically, the work is distinguished by the application of rigorous statistical validation techniques, including normality testing, P-value analysis, and correlation assessment, ensuring the robustness and reliability of the experimental findings. This level of analytical depth is relatively uncommon in regionally focused studies and strengthens confidence in the observed trends. Importantly, the study also contributes a practical dimension by identifying optimal aggregate proportions particularly the superior performance of 100% basalt and the highly efficient 75% basalt–25% limestone blend thereby offering actionable guidance for engineers and practitioners. By aligning material performance with local availability, the research supports the development of cost-effective and sustainable concrete solutions. Overall, this work not only enriches the scientific understanding of hybrid aggregate systems but also establishes a foundational framework for future investigations aimed at optimizing concrete mixtures in similar environmental and infrastructural contexts.

4. Conclusions, limitations, and Outlook

This study examined the effects of partially and fully replacing natural coarse aggregates with basalt and limestone aggregates in M25-grade concrete. The experimental results demonstrate a clear relationship between aggregate composition and concrete performance. In particular, increasing the proportion of basalt aggregate significantly enhances compressive strength across all curing ages. The mix containing 100% basalt aggregate exhibited the highest strength values, with improvements of approximately 26.8%, 10.9%, and 14.9% at 7, 28, and 56 days, respectively, compared to the control mix. Mixtures incorporating both basalt and limestone showed intermediate performance, with strength decreasing progressively as limestone content increased. Concrete made with 100% limestone aggregate recorded the lowest compressive strength. The superior performance of basalt-based concrete can be attributed to its higher density, lower porosity, and reduced water absorption, which contribute to improved interfacial bonding between the aggregate and cement paste. This results in a denser microstructure and more efficient load transfer. In contrast, the relatively lower strength of limestone-rich mixes is likely due to higher water absorption and weaker aggregate–paste interaction.

Despite these promising findings, several limitations should be acknowledged. The study was confined to M25-grade concrete under controlled laboratory conditions, which may not fully represent in-situ performance under varying environmental and loading conditions. Additionally, the investigation focused primarily on compressive strength, without addressing long-term durability aspects such as resistance to freeze–thaw cycles, sulfate attack, or chloride ingress. The use of aggregates from a single geological source and the relatively limited sample size may also restrict the broader applicability of the results. Based on the findings, basalt aggregate is recommended for use in structural concrete applications where higher strength and improved performance are required, such as foundations, columns, and pavements. For practical implementation, partial replacement (e.g., 75% basalt) may also be considered as it provides near-equivalent performance while potentially reducing material costs.

Future research should focus on evaluating the long-term durability performance of basalt-based concrete under aggressive environmental conditions, including permeability, shrinkage, and chloride penetration over extended curing periods. Further studies incorporating supplementary cementitious materials such as fly ash or silica fume are also recommended to enhance sustainability and optimize material performance. Finally, comprehensive economic and environmental assessments, including life-cycle cost analysis, are necessary to determine the feasibility of large-scale adoption of basalt aggregates in construction.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Author's Contribuitions

Conceptualization, Mona A. Rabih and A. Babiker; Methodology, Mona A. Rabih E. Elshaikh, and A. Babiker; Investigation, Mona A. Rabih and A. Babiker; Writing - original draft, Mona A. Rabih; Writing - review & editing, E. Elshaikh and A. Babiker; Software, Mona A. Rabih; Visualization, A. Babiker.

References

[1] Karasin A, Hadzima-Nyarko M, Işık E, Doğruyol M, Karasin IB, Czarnecki S. The Effect of Basalt Aggregates and Mineral Admixtures on the Mechanical Properties of Concrete Exposed to Sulphate Attacks. Materials 2022;15. https://doi.org/10.3390/ma15041581.

[2] Bawab J, El-Hassan H, Al Zagha H, El Gamal M. Characterization and recycling of waste gabbro stone powder as a sustainable cement replacement. Cleaner Waste Systems 2025;12. https://doi.org/10.1016/j.clwas.2025.100361.

[3] Al-Kharabsheh BN, Arbili MM, Majdi A, Alogla SM, Hakamy A, Ahmad J, et al. Basalt Fiber Reinforced Concrete: A Compressive Review on Durability Aspects. Materials 2023;16. https://doi.org/10.3390/ma16010429.

[4] Ismail NR. A Comparative Study of the Effect of Aggregate Type on the Strength and Abrasion Resistance of Concrete, Kurdistan Region, Iraq. Polytechnic Journal 2023;13. https://doi.org/10.59341/2707-7799.1722.

[5] Sharaky IA, Elamary AS, Alharthi YM. Effect of Waste Basalt Fines and Recycled Concrete Components on Mechanical, Water Absorption, and Microstructure Characteristics of Concrete. Materials 2022;15. https://doi.org/10.3390/ma15134385.

[6] Taha R, Al-Nuaimi N, Kilayli A, Salem A Ben. Use of local discarded materials in concrete. International Journal of Sustainable Built Environment 2014;3. https://doi.org/10.1016/j.ijsbe.2014.04.005.

[7] Ramteja P. Basalt Aggregate as Coarse Aggregate in High Strength Concrete Mixes. 2016.

[8] Ubi SE, Nkra PO, Agbor RB, Ewa DE, Nuchal M. EFFICACY OF BASALT AND GRANITE AS COARSE AGGREGATE IN CONCRETE MIXTURE. International Journal of Engineering Technologies and Management Research 2020;7. https://doi.org/10.29121/ijetmr.v7.i9.2020.769.

[9] Kılıç A, Atiş CD, Teymen A, Karahan O, Özcan F, Bilim C, et al. The influence of aggregate type on the strength and abrasion resistance of high strength concrete. Cem Concr Compos 2008;30:290–6. https://doi.org/10.1016/j.cemconcomp.2007.05.011.

[10] Al-Baijat HM. The use of basalt aggregates in concrete mixes in Jordan. Jordan Journal of Civil Engineering 2008;2.

[11] Ismail S, Ramli M. Effect of Different Moisture States of Surface-Treated Recycled Concrete Aggregate on Properties of Fresh and Hardened Concrete. World Academy of Science, Engineering and Technology International Journal of Civil, Architectural Science and Engineering 2014;8.

[12] Habibi A, Tavakoli H, Esmaeili A, Golzary A. Comparative life cycle assessment (LCA) of concrete mixtures: a critical review. European Journal of Environmental and Civil Engineering 2023;27:1285–303. https://doi.org/10.1080/19648189.2022.2078885.

[13] Ammar Babiker, Mona Adam. Enhancing M25 Concrete with Gabbro and Granite Aggregates: A Performance Evaluation. International Journal in Engineering Sciences 2025.

[14] British Standard Institution. Specification for Portland Cement. vol. BS 12. London: British Standard Institution; 1996.

[15] Specification for Portland cement. British Standards Institution; 1996.

[16] Kim S, Jung D, Kim J-Y, Mun J-H. Study on Early Age Concrete's Compressive Strengths in Unmanaged Curing Condition Using IoT-Based Maturity Monitoring. Buildings 2024;14:798. https://doi.org/10.3390/buildings14030798.

[17] Aggregates for concrete. British Standards Institution; 2008.

[18] Serdar Aydin HYMYY and HY. Effect of Aggregate Type on Mechanical Properties of Reactive Powder Concrete. ACI Mater J 2010;107. https://doi.org/10.14359/51663963.

[19] Keshavarz M, Pellet FL, Loret B. Damage and Changes in Mechanical Properties of a Gabbro Thermally Loaded up to 1,000°C. Pure Appl Geophys 2010;167:1511–23. https://doi.org/10.1007/s00024-010-0130-0.

[20] Rinaman W and MI. Revival: The Handbook of Software for Engineers and Scientists. vol. 2018. CRC Press: Boca Raton, FL, USA; 1959.