



Research Article

Enhancing M25 Concrete with Gabbro and Granite Aggregates: A Performance Evaluation

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ABSTRACT

Concrete is one of the most essential construction materials worldwide. Modifying its composition by incorporating different types of aggregates can significantly influence its properties. This study investigates the feasibility of using gabbro and granite stone as coarse aggregates in M25 grade concrete. An experimental program was designed to evaluate the mechanical and fresh properties of concrete incorporating various proportions of gabbro and granite aggregates. The concrete mixes were prepared using the British standard mix design method, and six combinations were tested with varying aggregate ratios. Nine specimens were cast for each mix and tested for workability and compressive strength at 7, 28, and 56 days of curing. The results showed that increasing the proportion of gabbro aggregates improved both workability and compressive strength. The 100% gabbro mix achieved the highest compressive strength with increases of 31.81%, 16.13%, and 17.8% over the control mix at 7, 28, and 56 days respectively. The findings support the suitability of gabbro as a sustainable and high-performance aggregate for concrete applications.


INTRODUCTION

Concrete stands as the most extensively used construction material globally, prized for its strength, moldability, and economic efficiency. Integral to its performance is the role played by aggregates, particularly coarse aggregates, which constitute up to 75% of concrete's volume. The characteristics of these aggregates critically

influence the mechanical properties, durability, and workability of concrete. Consequently, optimizing aggregate selection has emerged as a focal point in research aimed at improving concrete's structural performance and sustainability.[1,2]. Historically, crushed granite has served as the primary coarse aggregate in many regions, including Sudan. Granite is abundant, durable, and delivers satisfactory

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performance in conventional applications. However, increasing urbanization, environmental degradation, and the depletion of natural stone reserves have shifted the focus toward alternative aggregate sources. Among these, gabbro a dark, dense, and coarse-grained igneous rock has gained attention for its promising structural characteristics [2,3]. Gabbro exhibits high specific gravity, low porosity, and strong mechanical interlocking, all of which contribute to improved load-bearing capacity and reduced permeability. It also offers excellent abrasion and chemical resistance, which are vital for infrastructure exposed to harsh environmental conditions. These attributes have positioned gabbro as a competitive alternative to granite, particularly in regions where long-term durability and sustainability are paramount.[4,5].

Extensive international research supports the use of gabbro as a high-performance aggregate: Kilic et al. [5] concluded that concrete mixes incorporating gabbro aggregates exhibited superior compressive strength and abrasion resistance compared with those containing limestone or basalt. Their findings highlighted the influence of aggregate density and mineral composition on enhancing concrete performance. Taha and Al-Nuaimi [6] investigated the partial replacement of imported gabbro aggregates with steel slag and gravel in concrete production. Nine concrete mixes with varying proportions of steel slag and gravel were tested. All achieved the 28 MPa compressive strength requirement at 28 days, with the highest performance observed for the 100% steel slag mix. Gravel mixes showed lower strength, which improved with increasing gabbro content. Kishora and Mounika [7] examined the feasibility of using basalt aggregates in concrete by testing various basalt–limestone combinations. Laboratory evaluations included compressive strength, workability, and aggregate properties

such as abrasion resistance, specific gravity, and water absorption. Results indicated that the inclusion of basalt aggregates generally enhanced the overall performance of the concrete mix. Mahadeva [8] explored the replacement of conventional coarse aggregates with gabbro in concrete mixes. The study reported improved mechanical properties, particularly increased compressive strength, when gabbro aggregates were used. Ubi et al. [9] compared basalt and granite as coarse aggregates in concrete. While basalt exhibited slightly lower density, it demonstrated better impact resistance than granite. Structural tests revealed that basalt had higher tensile and flexural strengths, whereas granite showed marginally higher compressive strength. Overall, basalt was deemed more suitable for achieving high-strength concrete. Abdullahi et al. [10] assessed the suitability of basalt aggregates for concrete production by evaluating particle size distribution, water absorption, density, workability, and compressive strength at 7, 14, and 28 days, compared with a control mix made with limestone. Incorporating basalt from Biu, Borno State, improved overall concrete performance. Hassaballa [11] investigated the influence of crushed and uncrushed coarse aggregates on concrete compressive strength using the ACI and DoE mix design methods. Cube and cylinder specimens were tested at 7 and 28 days. ACI mixes generally achieved higher strengths than DoE mixes, except for M25 with crushed aggregates. The 7-day strength reached approximately 75% of the 28-day strength for ACI mixes and 73–77% for DoE mixes, depending on aggregate type. Beyond performance, the incorporation of gabbro aligns with sustainability objectives. As a naturally durable rock with low water absorption, gabbro facilitates reductions in cement and water usage key contributors to concrete’s environmental footprint. Studies by Kilic [2,5] and Neville [2,5]



underscore the value of selecting dense, non-reactive aggregates to improve durability while lowering lifecycle costs.

In Sudan, although gabbro is found in several regions including northeastern Khartoum, the Nuba Mountains, the Red Sea Mountains, the Ingessana Hills, and parts of Darfur its application in structural concrete remains minimal. The construction sector predominantly depends on natural uncrushed aggregates or granite, the latter incurring higher costs and transport-related emissions. Comparative evaluations of gabbro’s performance in local contexts are rare, highlighting a significant gap in engineering research [12,13].

This study addresses this gap by systematically evaluating M25 concrete mixes incorporating varying proportions of granite and gabbro. The work involves rigorous experimental testing of workability and compressive strength at multiple curing ages. Unlike prior studies that focused solely on strength, this research integrates fresh and hardened properties along with statistical analysis to offer a comprehensive evaluation.

Research methodology

Materials

To achieve the objectives of this study, an experimental program was conducted using locally available materials in Khartoum State. The following subsections describe the materials used and the test procedures implemented. Material testing plays a pivotal role in evaluating and ensuring the performance of concrete mixes. The following justifies the need for each of the conducted tests.

Cement

Ordinary Portland Cement (OPC) Type I, sourced from the Berber Cement Plant, was utilized in this study. Its fineness, standard consistency, and initial and final setting times were determined in accordance with BS 12:1996–2003 [14], with the results presented in Table 1. These tests are critical for evaluating cement performance. Fineness: Higher fineness increases the surface area available for hydration, thereby accelerating strength development and enhancing early-age properties [15]. Consistency and Setting Time: These parameters ensure that the cement possesses the required workability and setting characteristics, which are vital for large-scale applications to prevent premature hardening.

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 than 10 hours

Water

Portable tap water was used for both mixing and curing of the concrete specimens, meeting the general quality requirements of concrete mix water.

Fine aggregate

The fine aggregate (FA) employed in this study was sourced from Algitaina. It was washed, dried, and sieved to conform to the specified grading requirements. The material exhibited a specific gravity of 2.5 and a water absorption of 0.78%, as

shown in Table 2. Such tests are essential for verifying compliance with British Standards and ensuring consistent mechanical performance in hardened concrete [16].

Coarse aggregates

Three types of coarse aggregates were used in this study: natural uncrushed aggregate (NA) obtained from western Omdurman, crushed granite (GR) sourced from north-eastern Khartoum, and crushed gabbro (GA) also collected from north-eastern Khartoum. 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 2, while photographs of the materials are shown in Figure 1. These tests are

essential for assessing aggregate quality and suitability [16].

Table 2. Results of materials tests.

Test	Result				Standard range according to 1996–2003 [14]
	FA	NA	GR	GA	
SG (-)	2.50	2.69	2.72	2.90	Minimum 2.6
MC (%)	0.38	0.50	0.42	0.24	Maximum 2%
WA (%)	0.78	0.65	0.60	0.22	Maximum 2%



Figure 1. Materials used to produce M25 grade concrete.

Experimental program

Mix design and specimens preparation

Concrete mixtures were proportioned following the British Standard mix design method to achieve a target characteristic compressive strength of 25 MPa (M25 grade). Six different mix configurations were prepared, as summarized in Table 3. The control mix (NA100) consisted solely of natural uncrushed coarse aggregate (100% NA). The remaining five mixes incorporated varying proportions of GA and GR, with GA100GR0 containing 100% gabbro, GA75GR25 containing

75% gabbro and 25% granite, GA50GR50 containing equal proportions of each, GA25GR75 containing 25% gabbro and 75% granite, and GA0GR100 composed entirely of granite. All mixes were designed with a constant water–cement ratio and identical fine aggregate content to ensure uniformity in evaluating the effect of coarse aggregate composition on concrete properties. For each mix, nine cube specimens (150 × 150 × 150 mm) were cast, see Figure 2. Specimens were demolded after 24 hours and cured in water for 7, 28, and 56 days to assess strength development over time. Fresh concrete

workability was evaluated using the slump test in accordance with standard procedures. Compressive strength was measured using a calibrated compression testing machine at each curing age. This experimental program allowed for a direct comparison of the influence of varying gabbro-to-granite ratios on both the fresh and hardened performance of M25 grade concrete.



Figure 2. Specimens after casting.

Table 3. Concrete mixes.

Mixes	Percentage of coarse aggregates (NA%:GA%:GR%)
NA100	100%: 0.0%: 0.0%
GA100GR0	0.0%: 100%: 0.0%
GA75GR25	0.0%: 75%: 25%
GA50GR50	0.0%: 50%: 50%
GA25GR75	0.0%: 25%: 75%
GA0GR100	0.0%: 0.0%: 100%

RESULTS AND DISCUSSION

The results of the laboratory experiments are presented and discussed in this section. The performance of the six concrete mixes was evaluated based on two key parameters:

Table 4. Slump workability of M25 grade concrete mixes.

Mixes	NA100	GA100GR0	GA75GR25	GA50GR50	GA25GR75	GA0GR100
Slump (mm)	40	55.7	55.5	55	54.6	53.5

workability (slump test) and compressive strength at 7, 28, and 56 days.

Slump test result

The slump test was conducted to evaluate the workability of fresh concrete (Figure 3). Table 4 and Figure 4 present the slump values for all mix types. The results reveal that increasing gabbro content in the mix improved workability. As illustrated in Figure 3, the 100% gabbro mix exhibited the highest slump value (55.7 mm), while the control mix (100% natural aggregate) had the lowest (40 mm). Mixes incorporating 25–75% gabbro also showed consistent improvement in slump values. This confirms the positive influence of gabbro in enhancing fresh concrete workability. This enhancement is attributed to the lower water absorption and smoother surface texture of gabbro particles compared to natural and granite aggregates, allowing more free water to remain in the mix and reducing internal friction.



Figure 3. Slump test configuration.

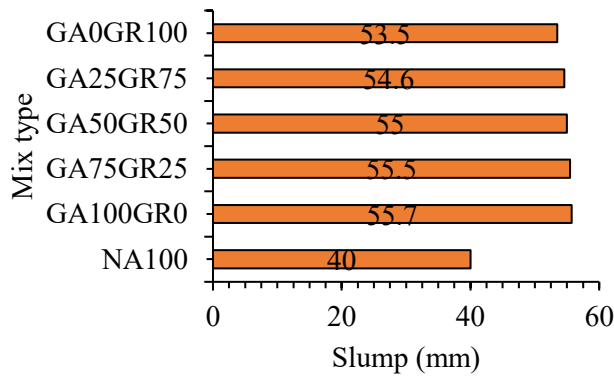


Figure 4. Slump workability of M25 concrete mixes.

Compressive strength test results

The compressive strength results obtained in this study (Table 5 and Figure 5) align closely with trends reported in previous investigations, further underscoring the mechanical superiority of gabbro aggregates. In the present work, the GA100GR0 mix (100% gabbro) consistently outperformed all other blends, achieving 29.0 MPa, 36.0 MPa, and 43.0 MPa at 7, 28, and 56 days, respectively representing strength gains of approximately 31.8%, 16.1%, and 17.8% compared with the control mix (NA100). Intermediate mixtures displayed a proportional decline in strength as the gabbro content decreased, with the GA0GR100 mix (100% granite) recording the lowest

performance among the gabbro–granite series. This strength enhancement is attributed to the high density, low porosity, and reduced water absorption of gabbro, which improve the interfacial bond between aggregate and cement paste, resulting in a denser microstructure with fewer internal voids. Such findings corroborate prior studies that documented substantial mechanical gains with gabbro incorporation. For instance, compressive strength increases of up to 62% have been reported, from 35.1 MPa for control concrete to 56.8 MPa for gabbro-based mixes, alongside flexural strength improvements exceeding 220% [17]. Similarly, waste gabbro utilization at 75% replacement yielded strength gains from 40.2 MPa to 51.8 MPa [18]. In high-strength concrete applications, gabbro has demonstrated exceptional potential, with compressive strengths approaching 200 MPa under optimized mix designs, coupled with notable enhancements in flexural performance attributed to its high intrinsic strength and rough surface texture [19]. Collectively, these results confirm that gabbro is a highly effective coarse aggregate for improving both the mechanical capacity and durability of concrete across a range of applications.

Table 5. Compressive strength of M25 concrete at various ages.

Curing age (day)	Compressive strength (MPa)					
	NA100	GA100GR0	GA75GR25	GA50GR50	GA25GR75	GA0GR100
7	22	29	27	26.5	27	25.5
28	31	36	35.5	35	33	32
56	36.5	43	40	38	37	36.5

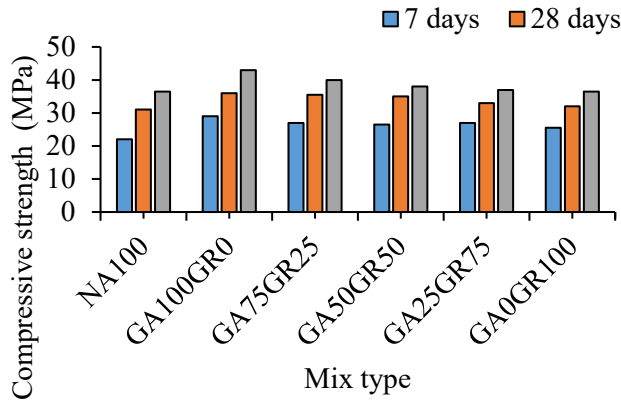


Figure 5. Compressive strength of M25 concrete at different ages.

Statistical analysis

A probability plot was generated to evaluate the normality of the compressive strength data (in N/mm²). 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)].

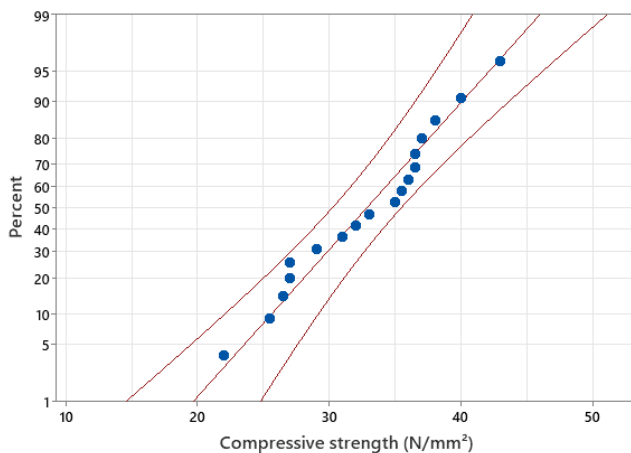


Figure 6. A probability plot of compressive strength.

The plot shows in Figure 6 that the data points are closely aligned with the reference line and fall within the 95% confidence bounds, indicating a strong fit to the normal distribution. The p-value of

0.502 exceeds the standard significance threshold ($\alpha = 0.05$), suggesting no significant deviation from normality. Moreover, the low Anderson-Darling value (0.324) further supports the assumption that the data are normally distributed. The high correlation coefficient ($R^2 = 0.95$) confirms a strong linear relationship between the observed values and the expected normal quantiles. These results validate the use of parametric statistical methods in subsequent analyses and confirm the appropriateness of assuming normality for the compressive strength data.

Novelty in comparison with related research

This study distinguishes itself from prior research by its focused local contextualization within Sudan, addressing a critical gap in the comparative evaluation of granite and gabbro aggregates under rigorously controlled laboratory conditions. Unlike many previous works that often examine aggregate properties in isolation or in broader geographic contexts, this research uniquely integrates both fresh and hardened concrete properties, systematically quantifying how aggregate composition influences workability and compressive strength across multiple curing periods (7, 28, and 56 days). Moreover, the application of robust statistical analyses, including P-value testing and Pearson correlation, provides a level of methodological rigor rarely seen in regional studies, ensuring the validity and reliability of the findings. This dual emphasis on empirical measurement and analytical validation not only reinforces the practical viability of gabbro as a sustainable, high-performance aggregate alternative but also offers actionable insights tailored to Sudan’s construction sector. Consequently, the study advances existing knowledge by laying a foundational framework for

future research on aggregate optimization in similar environmental and infrastructural settings.

Conclusions, limitations, and Outlook

This study investigated the effects of substituting granite with varying proportions of gabbro aggregate in M25-grade concrete. The results show that increasing gabbro content markedly improves both compressive strength and workability. Mixes containing 100% gabbro consistently delivered the highest performance, with strength gains of 31.81%, 16.13%, and 17.80% at 7, 28, and 56 days, respectively, compared with the control. These enhancements are attributed to the superior physical characteristics of gabbro, including higher specific gravity, lower porosity, and reduced water absorption. Statistical analysis confirmed the robustness of the findings, with a p-value of 0.502 indicating no significant deviation from normality and a Pearson correlation coefficient of 0.95 demonstrating a strong positive association between gabbro content and compressive strength. These results align with previous literature and highlight gabbro's potential as a high-performance replacement for conventional coarse aggregates.

Despite these promising outcomes, the study has several limitations. The investigation was limited to M25-grade concrete under controlled laboratory conditions, which may not fully capture field performance under variable service environments. The scope focused exclusively on mechanical properties, without assessing long-term durability factors such as resistance to freeze–thaw cycles, sulfate attack, or chloride ingress. Furthermore, only a single geological source of gabbro was tested, and the sample size for statistical evaluation was relatively modest, potentially limiting the generalizability of the conclusions.

To advance both scientific understanding and practical application, several recommendations are proposed. Construction practitioners are encouraged to consider gabbro aggregates for structural concrete in high-load, high-durability applications such as foundations, columns, and pavement layers. Future research should prioritize long-term durability assessments of gabbro-based concrete under aggressive environmental conditions, incorporating parameters such as permeability, shrinkage, and chloride penetration over extended curing periods of one year or more. Investigations into the combined use of gabbro aggregates with supplementary cementitious materials (e.g., fly ash, silica fume) could enhance sustainability while reducing cement consumption. Finally, comprehensive economic and environmental evaluations, including cost–benefit and life-cycle assessments, are recommended to quantify the feasibility and potential benefits of adopting gabbro aggregates in Sudan's construction industry.

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