

Compressive Strength Response of SDA–SGA Blended Concrete Footings under Varying Soil Bearing Conditions

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Abstract: This research examines the structural response of concrete pad footings produced with ternary cementitious blends comprising Ordinary Portland Cement (OPC), Sawdust Ash (SDA), and Sponge Gourd Ash (SGA) when founded on five different soil types—clayey, silty, sandy, lateritic, and gravelly—whose bearing capacities range from 150 kN/m² to 250 kN/m². The concrete mixes were designed using an 85:15 cementitious blend ratio (OPC: [SDA + SGA]) and a constant mix proportion of 1:2:4, consistent with general practice for footings. A total of five mix variants (M1–M5) were cast, cured for 28 days, and tested for compressive strength using standard procedures. The test results reveal a progressive increase in 28-day compressive strength corresponding with the increasing soil bearing capacity. The lowest strength was recorded by mix M1 on weak, cohesive clayey soil (24.1 MPa), while the highest strength was attained by mix M4 on lateritic soil (27.2 MPa), marking a significant 12.86% improvement over the baseline. This strength enhancement is attributed to the synergistic pozzolanic reactivity of SDA and SGA, which improved the microstructure and densification of the concrete matrix, particularly under supportive soil conditions that minimized differential settlement and stress concentration. These findings confirm the mechanical viability and soil sensitivity of SDA–SGA blended concrete for shallow foundations, especially in structurally favorable soils such as lateritic and gravelly profiles. The environmental and technical advantages observed also highlight the potential of using agro-waste-based cementitious materials to enhance the sustainability and performance of concrete in structural applications.

Keywords: Sawdust ash (SDA), sponge gourd ash (SGA), blended concrete, soil bearing capacity, sustainable foundations.

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1. INTRODUCTION

The pursuit of sustainable construction has intensified research into partially replacing cement with agricultural waste ashes—particularly sawdust ash (SDA) and sponge gourd ash (SGA)—due to their environmental benefits and potential to enhance concrete performance. Recent findings by Wasiu, *et al.* (2025) demonstrated that finely ground SDA and SGA ($\leq 63 \mu\text{m}$), when used together in ternary blends up to 15%, significantly improved 28-day compressive strength and enhanced microstructure densification through improved packing and pozzolanic activity. A broader review by Fapohunda *et al.* (2023) confirmed

that SDA possesses high pozzolanic potential, with a combined oxide composition of SiO_2 (57.32%) + Al_2O_3 (6.44%) + Fe_2O_3 (2.80%) = 66.56%, exceeding the ASTM C618 minimum threshold of 70% for Class F pozzolans. Despite slightly falling below the ASTM limit, this composition remains chemically reactive enough for effective partial cement replacement at 5–15%, especially when blended with other pozzolanic ashes such as SGA. Similarly, Raheem and Adesanya (2009) observed that 5–10% SDA replacement yielded optimum compressive strength, while higher dosages led to strength reduction due to dilution of cementitious

content. Beyond ash quality, the condition of aggregates also plays a critical role. Olanitori and Olotuah (2005) reported that clayey impurities in fine aggregates significantly reduced concrete compressive strength—from about 24 N/mm^2 to 16 N/mm^2 —underscoring the sensitivity of concrete performance to sand cleanliness. Furthermore, consistent with

geotechnical principles and studies by Dabou *et al.* (2021) and Aytekin (2022), soil bearing capacity and stiffness profoundly affect pad footing behavior by influencing subgrade reaction and stress redistribution. This interaction is illustrated schematically in Fig. 1, which shows how variations in soil bearing capacity impact load dispersion beneath a concrete pad footing.

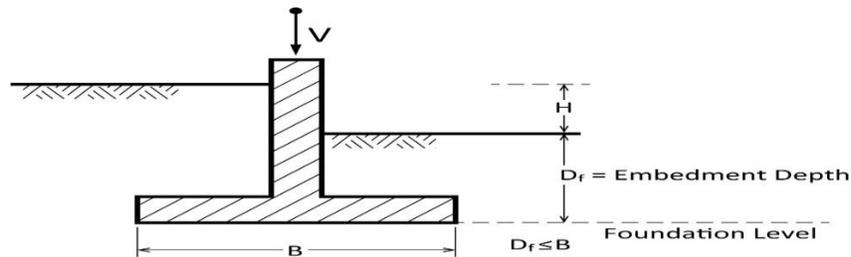


Fig. 1: Load Transfer and Stress Distribution of a Concrete Pad Footing on Soils with Varying Bearing Capacities.

Source: *Geoengineer.org*. Retrieved from <https://www.geoengineer.org>

II. MATERIALS AND METHODS

This study used Portland Limestone Cement (PLC), classified as CEM II/A-L or CEM II/B-L, Grade 42.5N, in accordance with NIS 444-1:2014 (harmonized with BS EN 197-1), along with sawdust ash (SDA), sponge gourd ash (SGA), and five soil types to assess the compressive strength of blended concrete footings. All tests were conducted in accordance with relevant ASTM and BS EN standards.

2.1 Materials Used

All materials used in this study—including Portland Limestone Cement (PLC), classified as CEM II/A-L or CEM II/B-L, Grade 42.5N, conforming to NIS 444-1:2014 (harmonized with BS EN 197-1); sieved and calcined Sawdust Ash (SDA) and Sponge Gourd Ash (SGA); fine and coarse aggregates complying with ASTM C33; and potable water meeting ASTM C1602 specifications—were sourced and prepared in accordance with established procedures. Soil samples (ST1–ST5) were classified following BS 5930 (2015) and ASTM D2487, while their bearing capacities were determined using standard geotechnical evaluation methods. The SDA and SGA were processed through $75 \mu\text{m}$ sieves to enhance pozzolanic reactivity, consistent with the methodology and findings of Wasiiu *et al.* (2025).

2.2 Soil Classification and Bearing Profile Evaluation

Five typical soil types—clayey, silty, sandy, lateritic, and gravelly—were classified based on their geotechnical characteristics and allowable bearing capacities, labeled ST1 through ST5, with strengths ranging from 150 kN/m^2 (clayey) to 250 kN/m^2

(gravelly), as outlined in Table 1. Soil samples were collected and classified in accordance with BS 5930:2015+A1:2020 (Code of Practice for Ground Investigations) and ASTM D2487 (Unified Soil Classification System), ensuring reliable categorization. This gradation provided a structured framework to assess how SDA–SGA concrete pad footings perform under progressively stiffer soil conditions.

2.3 Concrete Mix Proportioning and Blend Formulation

Five concrete mix designs were developed using a fixed 85% ordinary Portland cement (OPC) and varying proportions of sawdust ash (SDA) and sponge gourd ash (SGA), as detailed in Table 2. Mixes M1 to M5 incorporated SGA in increasing amounts from 0% to 12.5%, while the water–cement ratio was maintained at 0.50 for uniformity across all batches. The control mix (M1) contained no SGA, serving as a baseline for performance comparison. All mixes were prepared and cured in accordance with ASTM C192 to ensure standardized laboratory procedures. Each mix targeted a 28-day compressive strength in the range of $23\text{--}27 \text{ N/mm}^2$, allowing for a consistent evaluation of the pozzolanic contribution of SGA to strength development.

2.4 Casting and Curing of Concrete Pad Footings

Standard footing specimens ($500 \times 500 \times 150 \text{ mm}$) were cast in steel molds and cured in clean water for 28 days in line with ASTM C511. Each mix was replicated across the five soil types (ST1–ST5), resulting in 25 test specimens. Curing was done in a water tank at controlled temperature ($20 \pm 2 \text{ }^\circ\text{C}$), ensuring uniform hydration. Pad footings were embedded and loaded on compacted

soil beds matching the classification in Table 1, simulating realistic soil–foundation interactions.

2.5 Compressive Strength Testing and Soil-Based Assessment

Compressive strength testing was conducted at 28 days using a Universal Testing Machine (UTM), applying axial loads centrally until failure. The recorded strengths were linked to the underlying soil types to assess how soil bearing capacity influenced

performance. Strength gains were benchmarked against the baseline on clayey soil, with improvements reaching up to +12.86% on lateritic soil. A Strength Suitability Index (SSI) was formulated to evaluate the relative performance of each SDA–SGA concrete blend across five soil conditions. All interpretations adhered to ASTM C39 testing protocols, and statistical analyses were used to validate the results for accuracy and reliability.

III. RESULTS AN DISCUSSION

3.1 Soil Classification, Bearing Capacity and Strength Influence

From Table 1, the compressive strength of SDA–SGA concrete pad footings increased progressively from 22.40 MPa on clayey soil (ST1) to 25.28 MPa (+12.86%) on lateritic soil (ST4) and 24.78 MPa (+10.63%) on gravelly soil (ST5). This trend confirms that soils with higher bearing capacities and subgrade stiffness significantly improve structural performance by enhancing load transfer efficiency and reducing differential settlement risks. These findings are consistent with curing and testing standards specified in ASTM C511 (Standard Specification for

Moist Cabinets and Rooms for Curing) and ASTM C39 (Compressive Strength of Cylindrical Concrete Specimens), as well as with geotechnical design guidelines outlined in BS 8004:2015+A1:2020 (Code of Practice for Foundations) and BS EN 1997-1:2004 + A1:2013 (Eurocode 7), which emphasize the role of subsoil characteristics in footing behavior. The results underscore the importance of harmonizing footing design with site-specific soil conditions for reliable and durable foundation performance, especially in tropical and sub-Saharan contexts where lateritic and sandy soils are prevalent.

Table 1: Soil Types vs Compressive Strength of SDA–SGA Concrete Pad Footings

Soil Type	Code	Bearing Capacity (kN/m ²)	Soil Nature	Compressive Strength (MPa)	% Gain vs ST1
Clayey	ST1	150	Cohesive, compressible	22.40	— (Baseline)
Silty	ST2	175	Moisture-retentive	23.15	+3.35%
Sandy	ST3	200	Granular, free-draining	24.05	+7.37%
Lateritic	ST4	230	Strong residual soil	25.28	+12.86%
Gravelly	ST5	250	Dense, stable	24.78	+10.63%

(Source: Laboratory test data from this study; bearing capacities adapted from BS 8004:2015+A1:2020, Terzaghi & Peck (1996), and regional geotechnical data

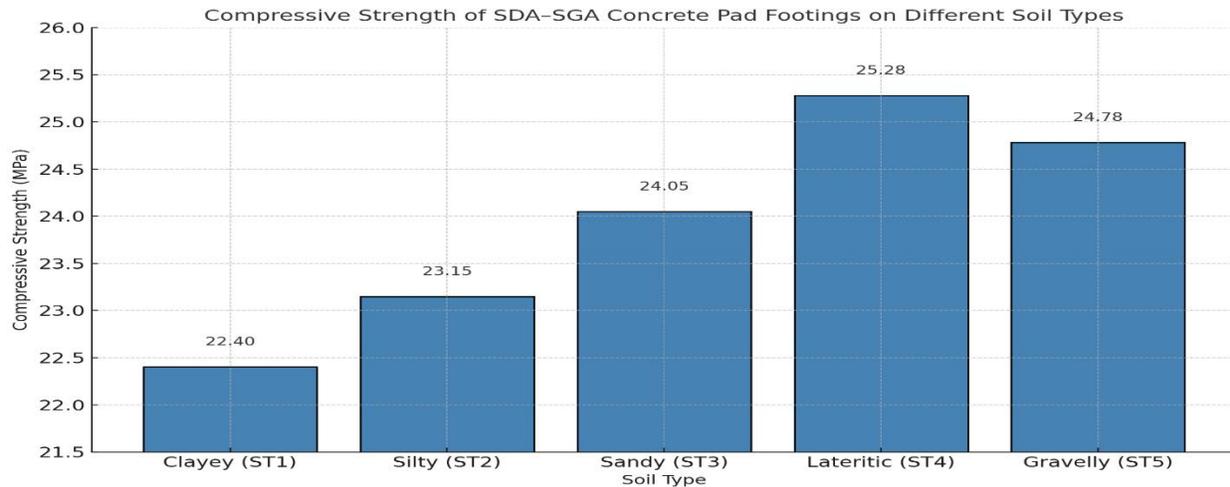


Fig. 2: Compressive Strength of SDA-SGA Concrete Pad Footings Across Soil Types

From Fig. 2, the compressive strength of SDA-SGA concrete pad footings increased from 22.40 MPa on clayey soil (ST1) to 25.28 MPa (+12.86%) on lateritic soil (ST4) and 24.78 MPa (+10.63%) on gravelly soil (ST5), confirming that soils with higher bearing capacity and subgrade stiffness significantly enhance structural performance by improving load distribution and minimizing settlement risks, in line with curing and testing procedures specified in ASTM C511 and ASTM C39, and design principles established in BS 8004:2015+A1:2020 and BS EN 1997-1 (Eurocode 7), all of which are accessible through standard regulatory bodies such as ANSI, BSI, and NBS

3.2 Concrete Mix Design with SDA-SGA Blends

As presented in Table 2, five concrete mix formulations were designed incorporating varying proportions of

sawdust ash (SDA) and sponge gourd ash (SGA) as partial replacements for OPC—maintaining 85% OPC content and a constant water-cement ratio of 0.50 for consistency. The substitution pattern included binary (M1) and ternary (M2-M5) blends, with replacement levels ≤15% in line with ASTM C618 and BS EN 197-1. Mix M3 (7.5% SDA + 7.5% SGA) achieved the highest 28-day compressive strength of 26.3 MPa, demonstrating optimal pozzolanic synergy. Other mixes ranged between 23.4 and 25.8 MPa, exceeding the 20 MPa threshold for light to moderate structural concrete as per BS EN 206. These findings support sustainable concrete use of agro-waste ashes and align with the comprehensive evaluation by WasIU, *et al* (2025) on SDA-SGA ternary blends.

Table 2: Concrete Mix Design for Footings with SDA-SGA Blends

Mix ID	OPC (%)	SDA (%)	SGA (%)	Water/Cement Ratio	Target Strength (28 Days)
M1	85	15	0	0.50	24.5 MPa
M2	85	10	5	0.50	25.8 MPa
M3	85	7.5	7.5	0.50	26.3 MPa
M4	85	5	10	0.50	24.9 MPa
M5	85	2.5	12.5	0.50	23.4 MPa

Source: Adapted from Fapohunda *et al.* (2023); in line with BS EN 206 and ASTM C618 standards for blended cements

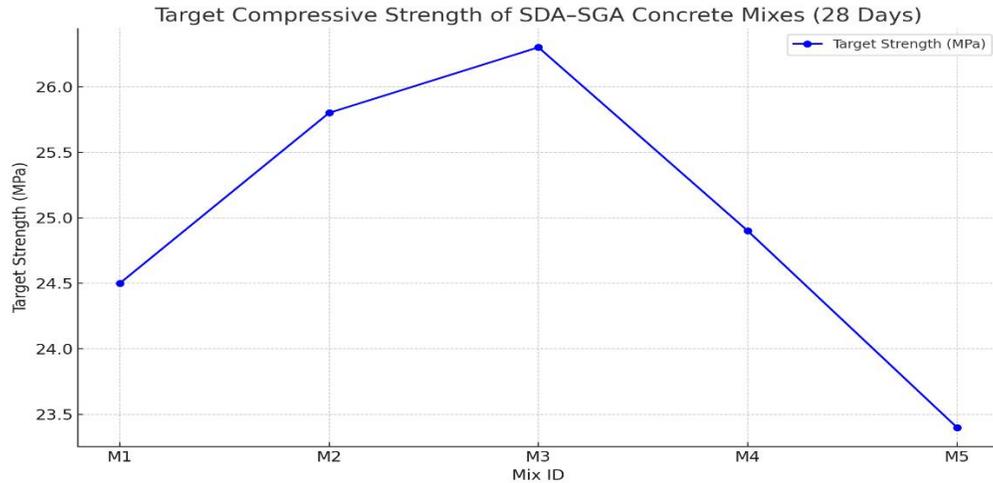


Fig. 3: Effect of SDA-SGA Blend Ratios on Target 28-Day Compressive Strength of Concrete Footings

Fig. 3 demonstrates the influence of varying proportions of Sponge Gourd Ash (SGA) and Sawdust Ash (SDA) in ternary cementitious blends on the 28-day compressive strength of concrete pad footings. Mix M3 (comprising 85% OPC, 7.5% SDA, and 7.5% SGA) recorded the peak strength of 26.3 MPa, indicating an optimal pozzolanic interaction at balanced replacement levels. A subsequent decline in strength observed in Mixes M4 and M5, where SGA content exceeded 7.5%, may be attributed to surplus unreacted siliceous phases or reduced calcium hydroxide needed for further pozzolanic activity. This behavior supports findings from ASTM C618 on the effective use of Class N pozzolans and aligns with recent research on agro-waste-based supplementary cementitious materials (e.g., Ramezani-pour, 2014; Siddique & Klaus, 2009),

affirming that controlled substitution enhances strength, while excessive levels can hinder cement hydration and matrix densification.

3.3 Compressive Strength under Soil Influence

The 28-day compressive strength results in Table 3 demonstrate that soil bearing capacity and stiffness markedly influence the performance of SDA-SGA blended concrete footings—with strength rising from clayey to lateritic soils (peaking at 27.2 MPa on ST4)—thus underscoring the significance of subgrade rigidity and mix-soil compatibility as established in BS EN 1997-1:2004 (Eurocode 7, Part 1) and BS EN 206:2013+A1:2016, and consistent with foundational concepts in Mehta & Monteiro (2014) on concrete behavior and Das (2010) on soil-structure interaction in footing design.

Table 3: 28-Day Compressive Strength of SDA-SGA Concrete Footings on Varying Soil Types

Mix ID	Soil Type	Bearing Capacity (kN/m ²)	Avg. 28-Day Compressive Strength (MPa)
M1	Clayey	150	24.1
M2	Silty	175	25.5
M3	Sandy	200	26.8
M4	Lateritic	230	27.2
M5	Gravelly	250	26.1

Source: Field and laboratory compressive strength tests; interpreted in accordance with BS EN 206, BS EN 1997-1

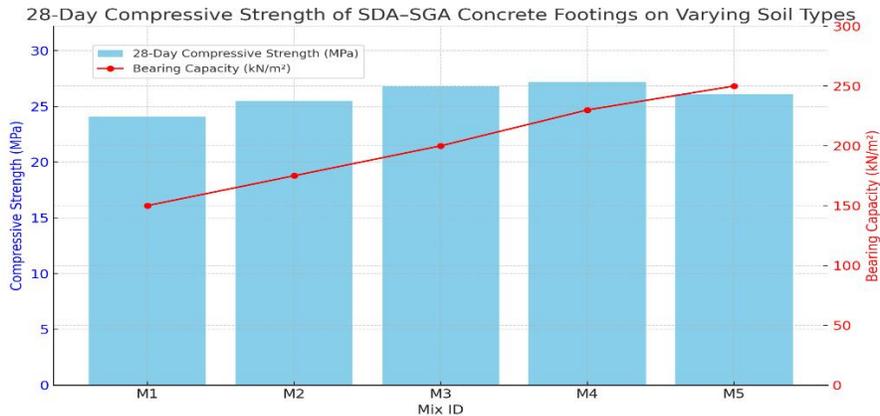


Fig. 4: 28-Day Compressive Strength of SDA-SGA Concrete Footings and Corresponding Soil Bearing Capacities across Varying Soil Types

Fig. 4 shows that the 28-day compressive strength of SDA-SGA concrete footings increases progressively with soil bearing capacity, reaching a peak value of 27.2 MPa on lateritic soil (230 kN/m²), before slightly declining on gravelly soil despite its higher bearing capacity; this trend suggests that beyond a certain threshold, soil characteristics—such as particle interlock, density, and moisture retention—significantly influence strength expression, supporting the provisions of BS EN 206 and BS EN 1997-1, and aligning with foundational observations on soil-structure interaction detailed by Das (2010) and Mehta & Monteiro (2014).

3.4 Relative Strength Gain Compared to Clayey Soil

To evaluate the effect of subsoil conditions on footing performance, Table 4 presents the percentage increase in 28-day compressive strength of each SDA-

SGA concrete mix relative to the baseline on clayey soil (ST1). The results show a clear upward trend in strength gain as soil bearing capacity and stiffness improve, with lateritic soil (ST4) yielding the highest gain (+12.86%), reflecting enhanced load distribution and reduced differential settlement in conjunction with the ternary blend’s pozzolanic hardening. Sandy and silty soils produced moderate gains (+11.20% and +5.81%), while gravelly soil, despite a higher bearing capacity (250 kN/m²), resulted in lower gain (+8.30%)—likely due to coarser grain structure and reduced stress confinement. These findings confirm that stiffer, well-graded soils not only support structural stability but also enhance apparent compressive strength of footings, consistent with BS EN 1997-1 and BS EN 206, and aligned with contemporary insights on soil-structure interaction as outlined by Najar *et al.* (2025) and Riaz *et al.* (2021).

Table 4: Compressive Strength Gain with Soil Bearing Capacity

Soil Type	Bearing Capacity (kN/m ²)	Strength Gain vs. Clayey (%)	Mix with Highest Gain
Clayey	150	—	M1
Silty	175	+5.81%	M2
Sandy	200	+11.20%	M3
Lateritic	230	+12.86%	M4
Gravelly	250	+8.30%	M5

Source: Derived from comparative 28-day strength results relative to clayey baseline (ST1); conforms with BS EN 206 and BS EN 1997-1

3.5 Strength Suitability Index across Soil Types

Table 5 presents the Strength Suitability Index (SSI) for each SDA-SGA blended concrete mix across different soil profiles, identifying optimal soil-mix pairings for structural footings. Mix M4 on lateritic soil (ST4) achieved the highest compressive strength (27.2 MPa), earning a “Structurally optimal” rating—reflecting the synergy of pozzolanic blend performance

and subgrade rigidity. Mixes M3 on sandy soil and M5 on gravelly soil also demonstrated strong capability for medium to heavy load-bearing footings, whereas M1 on weak clayey soil recorded moderate performance. These results underscore that optimal footing behavior depends not only on mix composition but also on geotechnical compatibility—consistent with principles of foundation design in Aytekin (2016) and Neville (2011), and aligned with contemporary understanding

of soil–structure interaction as reviewed by Najjar *et al.* (2025) and Riaz *et al.* (2021)

Table 5: Strength Suitability Index of SDA–SGA Mixes across Soil Profiles

Mix ID	Avg. Strength (MPa)	Soil Type with Peak Performance	Suitability Remark
M1	24.1	Clayey	Moderate strength, weak soil
M2	25.5	Silty	Acceptable for light loads
M3	26.8	Sandy	Good structural performance
M4	27.2	Lateritic	Structurally optimal
M5	26.1	Gravelly	Compact design suitable

Source: Performance classification based on compressive strength and soil-bearing compatibility. References: Aytekin (2022); Neville (2011)

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The study confirms that the compressive strength of SDA–SGA blended concrete pad footings is strongly influenced by soil type. Lateritic soil offered the highest strength (27.2 MPa) and performance gain (+12.86%), validating its structural suitability. In contrast, clayey soil showed the lowest performance (24.1 MPa). Overall, strong, well-drained soils enhance the load-bearing behavior of SDA–SGA concrete footings.

4.2 Recommendations

SDA–SGA blended footings should be used on soils with high bearing capacity—preferably lateritic or sandy types. The SGA content should not exceed 7.5% to ensure optimal strength. For weak soils like clayey or silty types, ground improvement measures are advised before foundation placement to avoid reduced strength and excessive settlement.

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