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# Performance Evaluation of Self-Compacting Concrete Incorporating Locally Sourced Okpella Limestone Powder and Granite Dust

**[1]OMOFUMA Bright Oseikhuemenand [2]UCHOLA Victor Onuche,[3]ADELOWOTofunmiCaleb, [4]OBEBEMonisola Dorcas and [5]OTOBO Victor**

1. Department of Civil Engineering, Faculty of Engineering and Technology, Ambrose Alli University, Ekpoma
brightfuma@aauekpoma.edu.ng
2. Department of Civil Engineering, Faculty of Engineering and Technology, Ambrose Alli University, Ekpoma
ucholavictor@aauekpoma.edu.ng
3.School of Engineering, Department of Civil Engineering, Babcock University, Ogun State
adelowot@babcock.edu.ng
4.School of Engineering, Department of Civil Engineering, Babcock University, Ogun State.
obebem@babcock.edu.ng
5. Department of Architectural Technology, National Institute of Construction Technology and Management, Uromi, Edo State, Nigeria
v.otobo@nict.ng.edu

**Corresponding Author: ucholavictor@aauekpoma.edu.ng**

***ABSTRACT***: *This study evaluated the performance of self-compacting concrete (SCC) incorporating locally sourced Okpella limestone powder and granite dust from Edo State, Nigeria, as partial cement replacement materials. The study focused on the physical characteristics of the materials, fresh properties, segregation resistance, and compressive strength development of the resulting concrete mixtures. SCC mixtures were produced with 0%, 10%, and 20% replacement levels and tested at 7, 14, and 28 days of curing. The results showed that increasing the proportion of Okpella fillers gradually reduced slump height, with the control mixture recording 240 mm, compared with 225 mm and 210 mm for the 10% and 20% replacement mixtures, respectively. Nevertheless, all mixtures maintained satisfactory workability and stability within relevant SCC requirements. Segregation indices remained below 15%, indicating adequate resistance to segregation. Compressive strength increased with curing age, although moderate strength reductions occurred with increasing filler content. Overall, Okpella limestone powder and granite dust demonstrated potential for sustainable SCC production without compromising essential performance requirements.*

***Keywords:*** *Self-compacting concrete; Okpella limestone powder; Granite dust; Compressive strength.*

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## 1. INTRODUCTION

Self-Compacting Concrete (SCC) is a highly flowable and stable concrete that spreads and consolidates under its own weight without mechanical vibration. Developed in Japan in the late 1980s, SCC improves construction efficiency, surface finish, and concrete quality while reducing labour requirements and problems associated with inadequate compaction (Okamura &Ouchi, 2003). However, its production may require substantial quantities of fillers and other materials, which can increase cost where suitable materials are not locally available.

Okpella, Edo State, possesses abundant limestone and granite resources whose fine products have potential for use in SCC. Utilizing these locally available materials could reduce dependence on externally sourced materials, minimize transportation costs, and promote sustainable construction. However, their suitability and influence on SCC performance require experimental evaluation.

The high cost and limited availability of suitable SCC constituent materials constitute barriers to its wider adoption in Nigeria. In addition, conventional concrete requires mechanical vibration, which may result in honeycombing and poor surface quality when compaction is inadequate. Despite the availability of limestone and granite-derived materials in Okpella, limited information exists on their effectiveness in SCC. This study therefore investigates their influence on the workability, segregation resistance, and compressive strength of SCC.

The aim **is** to evaluate the performance of SCC incorporating locally sourced Okpella limestone powder and granite dust.

The objectives of this study are to characterize the physical and particle-size properties of the selected Okpella limestone powder and granite dust, and to evaluate their effects at 10% and 20% replacement levels on SCC workability, segregation resistance, and compressive strength at 7, 14, and 28 days. The study also compares the modified SCC mixtures to assess their suitability for sustainable construction.

The study covers the characterization of Okpella limestone powder and granite dust, production of SCC mixtures at 10% and 20% replacement levels, and evaluation of their workability, segregation resistance, and compressive strength at 7, 14, and 28 days. The study is limited to laboratory-scale assessment of the selected fresh and hardened properties.

Self-Compacting Concrete (SCC) is a highly flowable, non-segregating concrete that can spread into place and fill formwork under its own weight without the need for mechanical vibration. It was first developed in Japan in the late 1980s to address labor shortages and to ensure proper compaction in heavily reinforced sections (Okamura &Ouchi, 2003). According to EFNARC (2002), SCC must satisfy three key performance criteria which are; filling ability, passing ability and segregation resistance. The advantages of SCC are; improved durability due to better compaction and reduced porosity (Neville, 2011).

**Table 1. Comparison of Conventional Concrete vs. SCC**

| Properties | Conventional Concrete | Self-Compacting Concrete (SCC) |
|---|---|---|
| Workability | Medium to low | High |
| Compaction | Requires vibration | No vibration required |
| Formwork filling | Moderate | Excellent |
| Segregation resistance | Moderate | High |
| Surface finish quality | Moderate | Superior |
| Labor requirement | High | Low |

**(Source: EFNARC, 2002)**

Compressive strength is a key performance indicator of SCC, influenced by factors such as cement content, water-to-cement ratio (w/c), aggregate type, and curing conditions. SCC generally exhibits equal or slightly higher compressive strength compared to conventional vibrated concrete (CVC) due to improved particle packing and reduced voids (Okamura &Ouchi, 2003).

**Table 2: Comparison of Compressive Strength of SCC and Conventional Concrete**

| Concrete Type | 7-day Strength (MPa) | 28-day Strength (MPa) | 56-day Strength (MPa) |
|---|---|---|---|
| Conventional Concrete | 18 – 25 | 30 – 45 | 40 – 55 |
| SCC | 20 – 28 | 35 – 50 | 45 – 60 |

(Source: EFNARC, 2002; Neville, 2011)

The modulus of elasticity (E) is a measure of concrete's stiffness and deformation under load. SCC typically has a slightly lower modulus than conventional concrete due to its higher paste content and lower coarse aggregate content (Deeb et al., 2012).

Equation for Modulus of Elasticity (BS EN 1992-1-1:2004):

$$E_{c=22(f_c)}\ ^{0.3} \qquad \text{Eq. 1}$$

Where Ec = Modulus of elasticity (GPa), fc = Compressive strength (MPa).

SCC exhibits improved durability due to its high density, low permeability, and uniform compaction. The durability aspects include chloride penetration resistance, carbonation depth, sulfate resistance, and freeze-thaw durability (Khayat, 1999). In terms of chloride penetration resistance, SCC demonstrates lower chloride penetration due to its denser microstructure, reducing the risk of reinforcement corrosion. SCC exhibits enhanced durability due to its self-compacting nature, which minimizes voids and increases resistance to chloride penetration and freeze-thaw cycles (Assaad et al., 2004).

SCC exhibits slightly higher shrinkage due to higher paste content and reduced aggregate volume. However, the shrinkage can be controlled by incorporating mineral admixtures such as silica fume or limestone powder (Bouzoubaa et al., 2001).

## III. MATERIALS AND METHODS

### 3.1 Research Design

This study adopted an experimental research design to evaluate the performance of self-compacting concrete (SCC) produced using locally available materials sourced from Okpella, Edo State, Nigeria. The investigation focused on the incorporation of Okpella limestone powder and granite dust as partial replacements for cement and filler materials in SCC.

The experimental programme consisted of three concrete mixtures: a control mixture containing no Okpella filler and two modified mixtures containing 10% and 20% replacement levels. The performance of the mixtures was evaluated through material characterization, fresh concrete testing and hardened concrete testing. The major properties investigated were particle-size distribution, workability, segregation resistance and compressive strength at 7, 14 and 28 days.

All experimental procedures were conducted in accordance with relevant British Standards, European Standards and established SCC guidelines, particularly the European Federation of National Associations Representing Producers and Applicators of Specialist Building Products (EFNARC) recommendations.

### 3.2 Materials

The materials used in the production of the SCC mixtures comprised cement, fine aggregate, coarse aggregate, Okpella limestone powder, Okpella granite dust, water and a polycarboxylate-based superplasticizer.

Portland limestone cement (PLC)obtained from a commercial supplier in Ekpoma, Edo State, was used as the primary binder. The cement complied with the requirements of BS EN 197-1:2011.

The cement was subjected to standard characterization tests, including consistency, setting time and soundness. The standard consistency was determined using the Vicat apparatus in accordance with BS EN 196-3:2016. The measured consistency was 30%. The initial and final setting times were 95 and 230 minutes, respectively. Soundness was determined using the Le Chatelier method, with an expansion of 1.5 mm. These results indicated that the cement was suitable for concrete production.

Locally available borrow-pit sand obtained from Ekpoma was used as fine aggregate. The material was air-dried, cleaned and subjected to particle-size distribution analysis before use. The sand complied with the requirements for fine aggregate specified in BS EN 12620:2013.

The particle-size distribution was determined by mechanical sieve analysis. A representative 500 g sample was oven-dried at approximately 105 °C for 24 hours and subsequently passed through a series of standard sieves. The mass retained on each sieve was measured and used to determine the percentage retained, cumulative percentage retained and percentage passing.

Crushed granite obtained from Okpella, Edo State, was used as the coarse aggregate. The aggregate was washed, oven-dried and subjected to sieve analysis to establish its particle-size distribution and suitability for SCC production. The aggregate complied with the relevant requirements of BS EN 12620:2013.

Limestone powder obtained from quarry operations in Okpella was incorporated as part of the local filler material. The material was dried and processed to obtain a fine powder suitable for use in SCC.

### 3.3 Methods

The fineness of the limestone powder was determined using the Blaine air-permeability method in accordance with BS EN 196-6:2018. The measured specific surface area was approximately 350 m²/kg. The limestone powder was selected because of its fine particle size and potential filler effect, which can improve particle packing and contribute to the stability and cohesiveness of SCC.Granite dust generated as a by-product of granite crushing operations in Okpella was used as a locally available fine filler. Its particle-size distribution, specific gravity, bulk density and water absorption were determined before incorporation into the concrete mixtures.

The specific gravity of the granite dust was determined using the pycnometer method in accordance with BS EN 1097-6:2013, while bulk density was determined in accordance with BS EN 1097-3:1998. The measured specific gravity was 2.71 and water absorption was 0.7%.

Potable water was used for concrete mixing and curing. The water was considered suitable for concrete production and curing in accordance with the requirements of BS EN 1008:2002.

A polycarboxylate-based high-range water-reducing admixture, Sika ViscoCrete-2100, was used to achieve the high flowability required for SCC without unnecessarily increasing the water content. The superplasticizer complied with the requirements of BS EN 934-2:2009. A dosage of 1.2% by mass of cement was adopted based on preliminary trials and was maintained for the different concrete mixtures.

Characterization of the constituent materials was carried out to establish their physical properties and suitability for SCC production. Sieve analysis was performed on the sand and granite dust using standard sieves and a mechanical sieve shaker. The samples were oven-dried before testing. Approximately 500 g of each representative sample was placed on the sieve stack and mechanically shaken. The material retained on each sieve was weighed and recorded.
The percentage retained and percentage passing were calculated from the measured masses. The resulting particle-size distribution was used to assess the grading characteristics and suitability of the materials for SCC production.

The specific gravity of the fine materials was determined using the pycnometer method. The test involved weighing the empty pycnometer, the pycnometer containing the dry sample, the pycnometer containing the sample and water, and the pycnometer containing water alone.

The specific gravity was determined from the relationship between the mass of the dry material and its displaced volume. The measured specific gravities were 2.71 for granite dust and 2.65 for sand.
The specific gravity of limestone powder was determined using the Le Chatelier flask method, with kerosene used as the displacement liquid to prevent undesirable reactions between the material and water.

Bulk density tests were conducted on the granite dust and sand. Both loose and compacted bulk densities were determined by filling a calibrated container with the material and determining the mass per unit volume.

The loose bulk density was obtained by allowing the material to fall freely into the container without compaction, whereas the compacted bulk density was determined after tamping the material in layers. The test results provided information required for appropriate volumetric proportioning of the concrete constituents. Water absorption was determined in accordance with BS EN 1097-6:2013. Representative samples were oven-dried, weighed, immersed in water for approximately 24 hours and subsequently surface-dried before weighing. The water absorption was calculated from the increase in mass between the oven-dry and saturated surface-dry conditions. The measured values were 0.7% for granite dust and 1.2% for sand.The SCC mix design was developed in accordance with EFNARC guidelines and BS EN 206:2013, using three mixtures: SCC-0% (control), SCC-10% (10% replacement), and SCC-20% (20% replacement). The replacement involved the combined Okpella limestone powder and granite dust.The total cementitious/filler content was adjusted according to the replacement level while the quantities of fine aggregate, coarse aggregate and water were maintained as specified in the experimental mix design.

**Table 3: Mix Proportions of SCC**

| Material | SCC-0% (kg/m³) | SCC-10% (kg/m³) | SCC-20% (kg/m³) |
|---|---|---|---|
| Cement | 450 | 405 | 360 |
| Okpella fillers | 0 | 45 | 90 |
| Fine aggregate (sand) | 850 | 850 | 850 |
| Coarse aggregate (granite) | 850 | 850 | 850 |
| Water | 180 | 180 | 180 |
| Superplasticizer | 1.2% | 1.2% | 1.2% |

The corresponding water-to-cementitious-material ratio based on the control cement content was approximately 0.40. The superplasticizer dosage was maintained at 1.2% to provide adequate flowability and stability.
All constituent materials were batched by mass using a digital weighing balance to minimize errors in proportioning. The mixing operation was carried out using a rotary concrete mixer.
The mixing procedure consisted of the following stages:
i. The cement, limestone powder, granite dust, fine aggregate and coarse aggregate were initially introduced into the mixer and dry-mixed for approximately 30 seconds to achieve uniform distribution.
ii. Water was gradually introduced while mixing continued.
iii. The required quantity of superplasticizer was added to the mixing water and incorporated into the concrete.
iv. Mixing continued for approximately 3–5 minutes until a homogeneous and cohesive SCC mixture was obtained.
v. The fresh concrete was subjected to workability and segregation-resistance tests immediately after mixing.

For compressive-strength testing, fresh SCC was placed into 150 mm × 150 mm × 150 mm cube moulds without mechanical vibration, relying on the self-compacting characteristics of the concrete to fill the moulds. The moulds were kept on a level surface and left undisturbed for approximately 24 hours.

After demoulding, the specimens were properly labelled according to mix identification and curing age and immersed in clean water until the required testing ages of 7, 14 and 28 days.

Fresh SCC properties were investigated immediately after mixing. The principal parameters considered were workability and segregation resistance.

The workability of the concrete was assessed using the slump-cone method. The test was conducted in accordance with the relevant provisions of BS EN 12350 for fresh concrete testing.

The slump cone was cleaned and placed on a flat, rigid surface. Fresh concrete was introduced into the mould and the surface was levelled. The mould was subsequently lifted vertically, allowing the concrete to deform under its own weight. The difference between the original height of the concrete and its final height was measured as the slump.

The measured values were used to compare the relative flowability of the control SCC and the mixtures containing Okpella fillers.

For SCC, the workability results were interpreted together with the observed flow behaviour and stability of the concrete. The same procedure was applied to all three mixtures to ensure consistency in comparison.

Segregation resistance was evaluated to determine the ability of the fresh SCC to maintain a uniform distribution of coarse aggregate during and after placement.

A representative fresh concrete sample was placed into a cylindrical container without mechanical vibration and allowed to remain undisturbed. After the prescribed standing period, the concrete was divided into upper and lower sections. The coarse aggregate was separated, washed and weighed from each section.

The segregation index was calculated from the difference in coarse aggregate content between the upper and lower portions of the sample. A lower segregation index indicated better resistance to segregation and improved mixture stability.

The measured segregation indices were compared with the accepted limits for SCC stability, with values below 15% considered indicative of satisfactory segregation resistance.

The hardened concrete investigation focused on compressive strength. Standard 150 mm cube specimens were prepared from each SCC mixture.

Following casting, the specimens were left in the moulds for approximately 24 hours. They were then demoulded, labelled and transferred to a curing tank containing clean water maintained at approximately 20 ± 2 °C**.**Three curing ages of 7, 14, and 28 days were considered in the study.

The use of these curing ages enabled the development of early, intermediate and conventional 28-day compressive strength to be compared among the different SCC mixtures.

Compressive strength was determined in accordance with BS EN 12390-3:2019. Prior to testing, each specimen was removed from the curing tank, surface-dried and examined for visible defects.

The dimensions and mass of each cube were recorded, after which the specimen was centrally positioned between the platens of a 2000 kN-capacity compression testing machine. Load was applied continuously at the prescribed rate until failure occurred.

For the 150 mm × 150 mm × 150 mm cubes, the loaded cross-sectional area was 22,500 mm².

The compressive strength of each mixture was determined at 7, 14 and 28 days. The results were subsequently compared to establish the effect of Okpella filler incorporation and curing age on strength development.

## IV. RESULTS AND DISCUSSION

### 4.1 Sieve Analysis Results

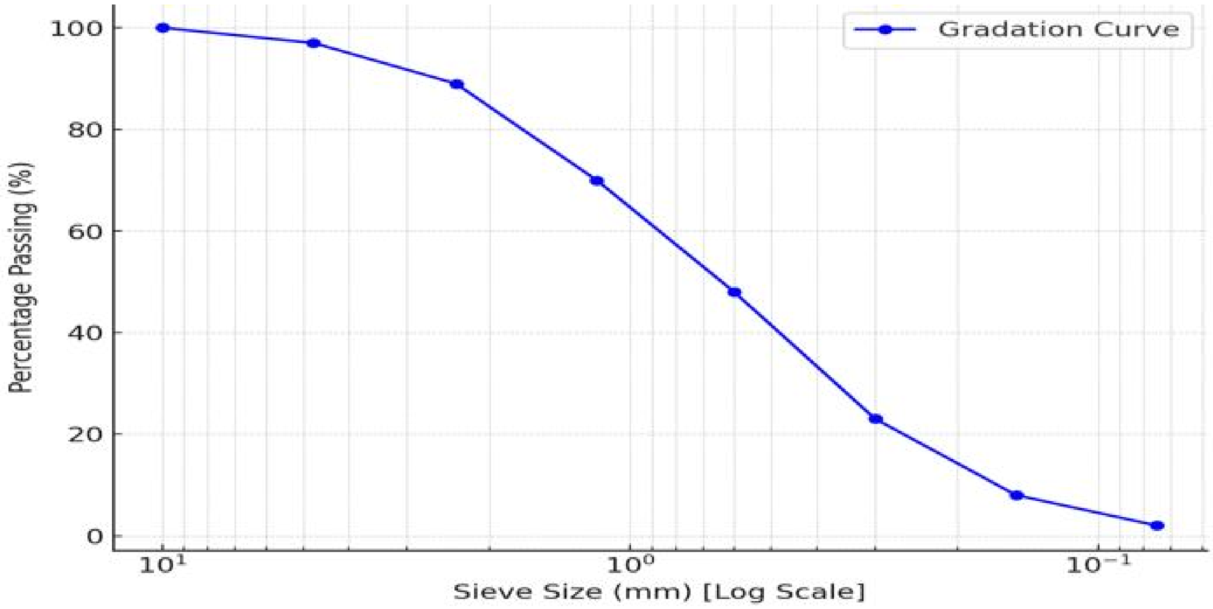


**Fig 1. Particle Size Distribution Curve for Ekpoma Borrow Pit Sand**

The Uniformity Coefficient (Cu) and Coefficient of Gradation (Cc) are important parameters in soil and aggregate classification. They are determined using the particle size distribution data.

The percentage passing through the 4.75 mm sieve is 97%, confirming that the sample qualifies as fine aggregate per BS EN 12620:2013. The percentage passing through the 0.150 mm sieve is 8%, ensuring minimal fine particles that could cause excessive water demand. The grading curve falls within the recommended zone for concrete sand, indicating good workability and compatibility for self-compacting concrete (SCC). The silt and clay content, measured separately as 2.5%, which is within the 3% allowable limit under BS EN 12620:2013

**a. Fresh Properties of SCC**

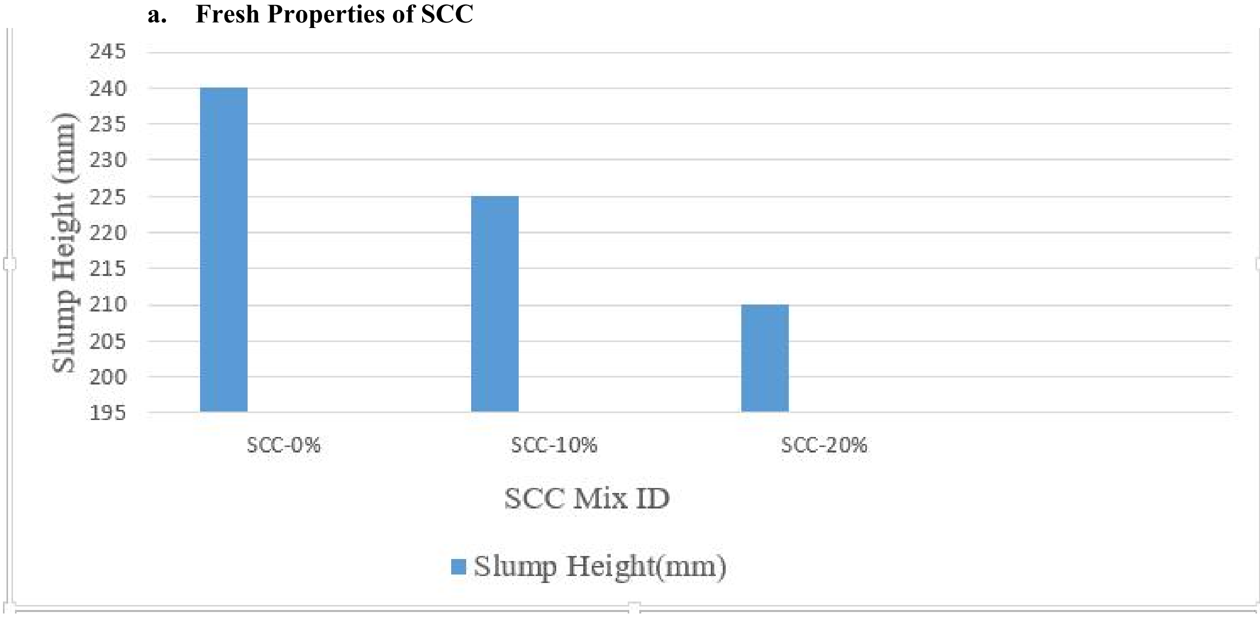


**Fig 2. Workability of SCC with Partial Replacement of Cement with Lime Stone Powder**

  

The SCC-0% (Control Mix) exhibited the highest slump height of 240 mm, indicating excellent workability and flowability, as expected for an SCC mix without fillers.AsOkpella fillers were introduced, the SCC-10% mix had a slightly reduced slump of 225 mm, while the SCC-20% mix had the lowest slump of 210 mm.This gradual reduction in slump height is due to the increasing replacement of cement with Okpella fillers, which likely affects the paste's cohesion and flowability.All three mixes exhibited a "True Slump" type, indicating uniform consistency without signs of shear or collapse failure. This suggests that despite filler replacement, the SCC retained its stability and workability.

The reduction in slump height with increasing filler content suggests that Okpella fillers increase the mix's viscosity, slightly reducing its free-flowing nature. However, the results are within acceptable limits for self-compacting concrete, meaning the mixes still possess sufficient flowability for SCC applications.

**4.3. Segregation Resistance**

**Table 4. Segregation Resistance Test Results**

| SCC Mix ID | Coarse Aggregate in Lower Half ($W_l$) (g) | Coarse Aggregate in Upper Half ($W_u$) (g) | Segregation Index (%) | Stability Classification |
|---|---|---|---|---|
| SCC-0% | 1200 | 1150 | 2.13% | Excellent Stability |
| SCC-10% | 1180 | 1125 | 2.39% | Excellent Stability |
| SCC-20% | 1165 | 1100 | 2.87% | Excellent Stability |

The segregation index values for all SCC mixes are below 15%, meeting the EFNARC (2002) and BS EN 12350-10:2010 requirements for self-compacting concrete stability. The low segregation index indicates that SCC with Okpella fillers maintains good cohesion and uniform distribution of coarse aggregates. The control mix (SCC-0%) had the lowest segregation index (2.13%), meaning it had the best segregation resistance. The SCC-10% and SCC-20% mixes also showed excellent stability, indicating that Okpella fillers do not negatively affect SCC stability. The SCC mixes with Okpella limestone powder and granite dust exhibit high segregation resistance, ensuring consistent workability, strength, and durability. No modifications to the mix design are required for segregation resistance, as all values are within acceptable limits.

**a. Hardened Properties**

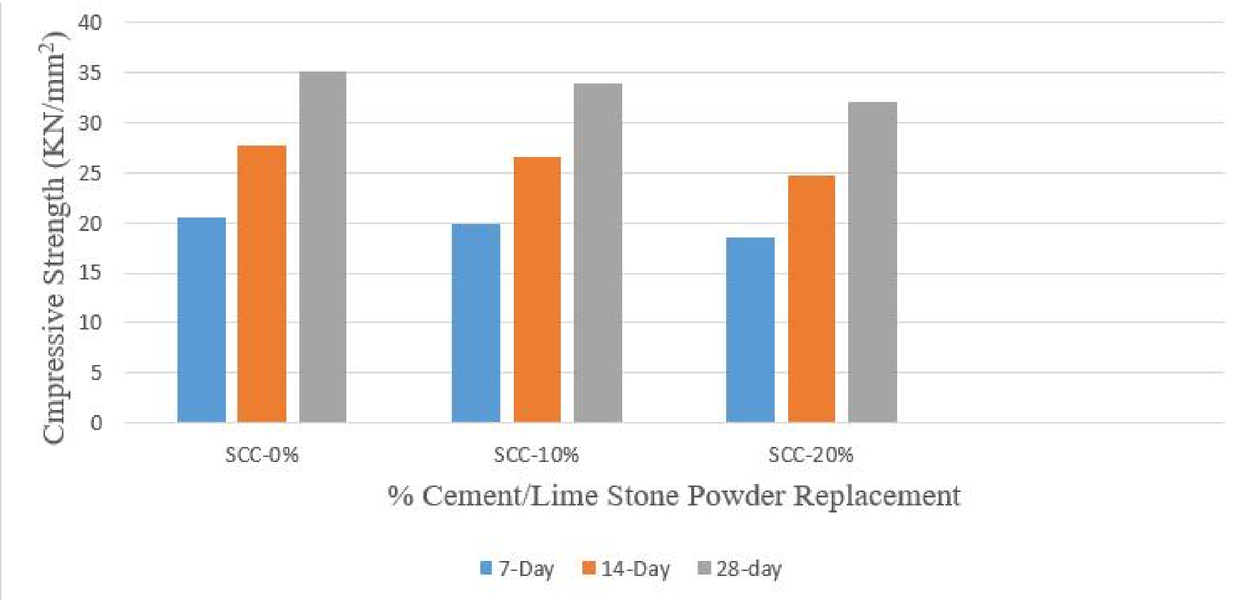


**Figure 3. Compressive Strength vs. % Replacement**

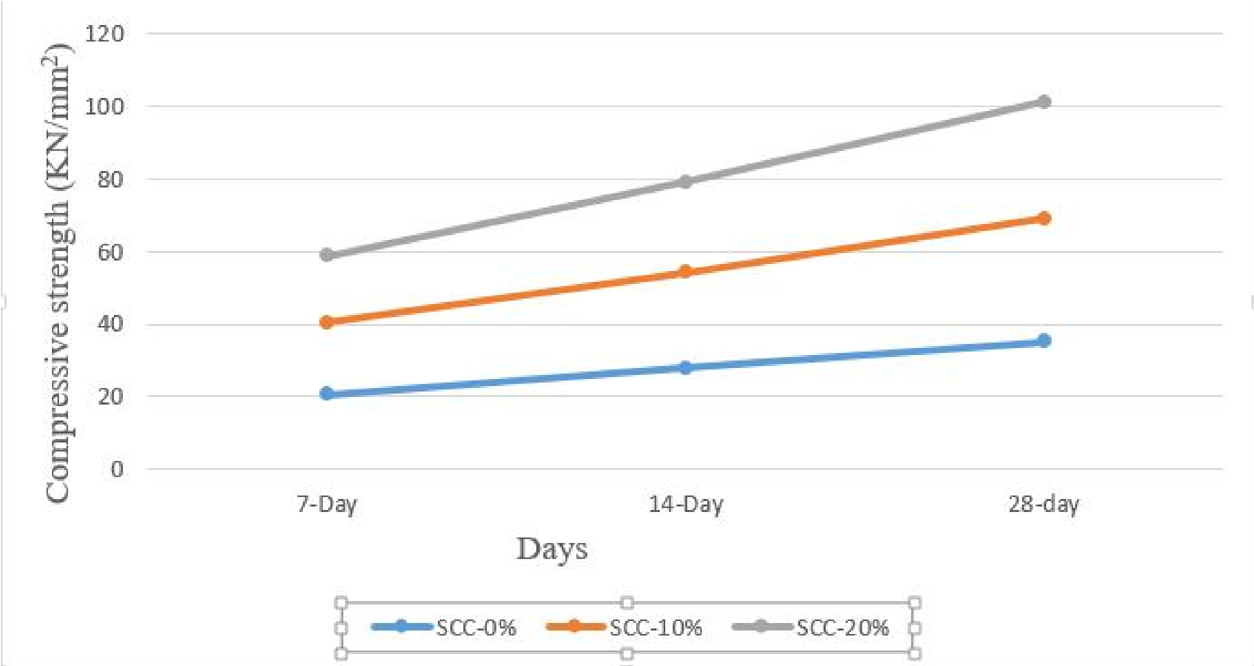


**Fig 4. Trend Line Graph of Compressive Strength vs. Days**

The compressive strength increased with curing time, as expected. The control mix (SCC-0%) exhibited the highest compressive strength at all curing ages. Partial replacement of cement with Okpella fillers (limestone powder and granite dust) slightly reduced the compressive strength.

The reduction in strength is attributed to the dilution effect of the fillers, which partially replace cement hydration products. All SCC mixes achieved satisfactory strength for structural applications. The 28-day strength values exceed 30 KN/mm², which is adequate for reinforced concrete elements in sustainable construction.

## IV. CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

This study evaluated the performance of Self-Compacting Concrete (SCC) incorporating locally sourced Okpella limestone powder and granite dust, with emphasis on workability, segregation resistance, and compressive strength. The results showed that increasing the filler content from 0% to 20% gradually reduced slump height from 240 mm to 210 mm, with SCC-10% recording 225 mm. Despite this reduction, all mixtures maintained satisfactory workability and self-compacting characteristics in accordance with EFNARC (2002) and BS EN 12350-10:2010 requirements.

The segregation results further demonstrated good stability, as all mixtures recorded segregation indices below 15%, while the control mixture recorded the lowest value of 2.13%. Compressive strength increased progressively with curing age, although the incorporation of Okpella fillers produced a slight reduction compared with the control mixture. Nevertheless, all mixtures achieved 28-day compressive strengths above 30 N/mm², indicating their potential suitability for structural applications. Overall, the findings establish that Okpella limestone powder and granite dust can be effectively utilized in SCC while maintaining satisfactory performance and supporting more sustainable use of locally available construction materials.

### 5.2 Recommendations

Based on the findings, the following recommendations are made:

i. The optimum Okpella filler content should be established through further mix optimization studies.

ii. Microstructural investigations using SEM and XRD should be conducted to better understand filler–cement interactions.

iii. Long-term durability properties, including resistance to carbonation, sulphate attack, and chloride penetration, should be investigated.

iv. Life Cycle Assessment and cost analysis should be undertaken to establish the environmental and economic benefits of using Okpella materials.

v. Field trials and pilot structural applications should be conducted to validate the laboratory findings under practical construction conditions.

vi. Future studies should investigate the combined use of Okpella materials with other supplementary cementitious materials to further improve the performance and sustainability of SCC.

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