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Sedimentary petrography and geo-mechanical assessment of some Cretaceous sandstone in parts of the Southern Benue Trough, south-eastern Nigeria

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Abstract: *An assessment of the petrographic and geo-mechanical properties of some exposed Cretaceous sandstones in parts of south-eastern Nigeria was carried out to determine the relationship between these two intrinsic properties of the sandstones. Routinely, petrographic analyses of rocks are often carried out as an easy procedure used to assess the mineralogical composition and therefore mechanical quality of rocks for construction purposes. Calcareous sandstones from four localities (Ngbo, Akpegu, Ezillo, and Abini) were tested for their petrographic, aggregate degradation (AD), and mechanical properties. The aggregate degradation was determined using the Los Angeles abrasion value (LAAV), aggregate impact value (AIV), and aggregate crushing value (ACV) tests.Petrographic analysis revealed two end-member textural characteristics for the sandstones: grain-supported and matrix- supported, and theyare composed of quartz grains, feldspar (plagioclase), fossil fragments and microcrystalline calcite (micrite). The rocks' ACVs and AIVs ranged from 16.34 to 26.29 % and 15.87 to 22.52 %, respectively, while the LAAVs varied from 38.62 to 53.1 %. The slake durability index is within the range of 91.1 to 96.7 % and the strength values of the studied rocks fall within the moderately strong category (25-50 MPa) except for the Ezillo and Abini sandstones (<25 MPa).The statistical relationship using a regression line between the mineralogical components and mechanical properties shows that the quartz content, micrite, and micrite plus fossil fragments have a significant correlation with strength, LAAV, ACV, and the slake durability index. The strong correlation between aggregate crushing value and micrite content shows that the proportion of micrite observed in a rock is of great importance, especially when subjected to applications where crushing forces is significant.It was also observed that the grain-supported samples exhibited better mechanical properties when compared with those that were matrix-supported.*

Keywords*: Calcareous sandstones, Petrographic analysis, Micrite,grain-supported, matrix-supported.*

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1.0 Introduction

The rapid growth of urbanization and infrastructure development worldwide has resulted in an unprecedented demand for construction materials, particularly rock aggregates used in road construction, foundations, concrete production, and other civil engineering applications. Consequently, the identification and characterization of locally available geological materials have become increasingly important for sustainable and cost-effective construction practices. This has become necessary because the failure to characterize the strength properties of rocks leads to engineering failures that may have been avoided if professional attention were placed on the choice of materials before their use (Kanji, 2014; Kamani & Ajalloeian, 2018; Ismail & Abdulwahid, 2021).Additionally, non-testing and evaluation of the available geological materials may hinder the use of some competent materials due to the failure of the less competent ones after the event of structural failures. Since it is an established fact that geological materials are inhomogeneous and non-consistent, that is, they vary greatly in their physical and mechanical properties within the same site or even the same geological formation; it becomes challenging to draw broad conclusions about the entire geological unit (Rodrigues, 1988; Edet, 2018). Thus, a thorough investigation including the physical, mechanical, and mineralogical characteristics is necessary for a strategic assessment of locally or regional distributed sedimentary rock resources (Kanji, 2014). Moreover, where deposits of adequate strength exist near construction sites, the high haulage costs for importing igneous or metamorphic aggregates from distant sources can be reduced drastically (Teme, 1991).

In addition to reducing transportation costs, the utilization of locally sourced aggregates requires a comprehensive understanding of their mineralogical and textural characteristics because these attributes exert significant control on their engineering performance. Petrographic investigations can therefore serve as an effective preliminary tool for predicting the durability and strength of rock materials before extensive laboratory testing is undertaken.

In situations where sufficient quantities of rock cores and aggregates cannot be easily extracted for sampling and testing, especially at the planning stage of a rock aggregate or quarry project, the relationships between rock mechanical properties and petrographic properties can be particularly useful. Furthermore, during the design stage, the petrographic features of these rocks can be used to forecast and evaluate the rock's quality for construction purposes. The petrographic analysis of rock offers significant insights into its mechanical behaviour under stress by studying its grain size, grain shape, fabric, grain boundaries, mineralogical composition and weathering (Irfan, 1996, Ademeso, 2024). As such, petrographic studies can most often provide a quick and reliable prediction of these rocks' strength properties (Pomonis et al., 2007; Yasir et al., 2018).

The relationship between petrographic characteristics and the physicomechanical behaviour of rocks has attracted considerable research attention because mineral composition, grain characteristics, cementation, pore structure, and textural relationships collectively influence rock strength and durability. Consequently, numerous studies have attempted to establish predictive relationships between petrographic parameters and engineering properties (Okon et al., 2023; Ademeso, 2024). Kamran et al., (2022) observed that the densely packed and compacted character of the investigated Pakistan limestone resulted in high strength and resistance to aggregate degradation. Additionally, they found that the strength of the rock is strongly correlated with the content of ooids and peloids, but the bioclast has an opposite relationship. In their study, Yusof & Zabidi, (2016), found weak connections between mineral composition and strength parameters in granitic rocks; these they suggested is of particular concern in the use of these materials for engineering purposes. Makani, 2014 opined that mineralogical composition, especially the proportion of quartz content, is one of the main properties controlling the rock strength of granitic aggregates**.** According to Pomonis et al., (2007), the mechanical characteristics of the dolerites under study were positively impacted by the abundance of secondary quartz content, whereas plagioclase content harmed the mechanical properties. In contrast to the influence of their mineralogical composition, Tamrakar et al., (2007) found that the textural characteristics of the Siwalik sandstones significantly affect their mechanical capabilities. According to the correlation study, the sandstones are highly influenced by the ratio of strong cement to total cement, packing density, grain to void contact, strong over weak contacts, void content, and concavo-convex contact. However, Yusof and Zabidi, (2016) noted that there are no specific mineralogical properties that can be relied on to determine the strength of rocks for the three types of rocks (igneous, sedimentary and metamorphic) since they have different mineral contents and discontinuities. Therefore, the correlations are best suited for local geology. Although several studies have investigated the relationship between petrographic attributes and mechanical properties in different lithologies worldwide, such relationships are highly dependent on geological setting, depositional environment, diagenetic history, and mineralogical composition. Consequently, empirical correlations developed for one geological terrain may not be applicable elsewhere. In southeastern Nigeria, particularly within the Southern Benue Trough, studies integrating detailed petrographic characterization with aggregate degradation and strength properties of calcareous sandstones remain scarce. This knowledge gap limits the development of reliable predictive models for assessing the engineering suitability of these widely utilized rock resources.

Southeastern Nigeria is underlain by extensive Cretaceous sandstone deposits that constitute one of the most important sources of construction aggregates in the region (Edet, 2018). These sandstones are employed in most building projects in southeastern Nigeria, particularly in Afikpo and surrounding areas, and are occasionally transported to neighbouring states such as Imo, Abia, and Enugu, where they are mostly used as foundation, floor finishing, and concrete components (Nwimo et al, 2021). Edet, (2018) demonstrated that these rocks have characteristics ranging from appropriate to unsuitable. Understanding the relationship between petrographic characteristics and mechanical behaviour would facilitate the rapid identification of suitable construction materials during preliminary site investigations and reduce the time and cost associated with extensive laboratory testing. Despite the widespread utilization of these sandstones in engineering projects, integrated studies that quantitatively relate their petrographic characteristics to aggregate degradation and strength properties are limited. As a result, the influence of mineralogical composition and textural attributes on their engineering performance remains inadequately understood.The aim of this study is to evaluate the relationship between petrographic characteristics and physicomechanical properties of selected calcareous sandstones from the Southern Benue Trough, southeastern Nigeria. Specifically, the study investigates how mineralogical composition, texture, and fabric influence aggregate degradation, durability, and strength characteristics. By integrating petrographic observations with standard geomechanical testing, the study provides locally derived empirical relationships that may serve as a basis for the preliminary assessment of sandstone quality for engineering and construction purposes. Physicomechanical testing and standard petrographic examination of thin sections using a polarizing microscope were carried out. Unlike previous investigations that primarily focused on either petrographic characterization or engineering properties independently, the present study combines quantitative petrographic analysis with aggregate degradation and strength testing to establish relationships that can be directly applied to engineering decision-making within the Southern Benue Trough. This study is intended to help engineers make preliminary engineering decisions during site investigations.

1.1 Geological Settings

The Benue Trough is a major NE–SW trending intracontinental sedimentary basin in Nigeria, extending for approximately 1000 km in length and 130 km in width. It contains a thick succession of Cretaceous sediments deposited during the evolution of the West and Central African Rift System (Ibe & Okon, 2021). (Ibe & Okon, 2021). It is sub-divided into the Northern Benue, Central Benue and Southern Benue Trough. This study considers sediments within the Southern Benue Trough. Sedimentation within the Southern Benue Trough commenced during the Albian with the deposition of the Asu River Group, which is locally intruded by mafic volcanic rocks (Uzuakpunwa, 1974). The Asu River Group is made up of shales, sandstones and siltstones and has a thickness of approximately 2000m (Adighije, 1981). It is laterally correlatable with the Awi Formation of the Calabar Flank (Okon et al 2023, 2026a; Kudamnya et al. 2026).The Eze-Aku Group overlies the Asu River Group and is composed predominantly of shales with subordinate sandstone interbeds. Although they are widely considered to be non-conformable, their precise relationship to the Asu River Group is unclear. The thickness of the Eze-Aku Group is approximately 1000m in subsurface continuation; represented by calcareous shales, siltstones, sandstones and thin beds of shelly limestone (Ojong et al 2018; Ibe and Okon 2021; Okon et al., 2026b). It has been dated Turonian (Adighije, 1981; Cratchley & Jones, 1965), with deposition beginning in the latest Cenomanian (Offodile & Reyment, 1977). The Awgu Formation, located stratigraphically above the Eze-Aku Formation, is composed of marine fossiliferous, grey bluish shales, limestones, and calcareous sandstone, most likely of Late Turonian to Coniacian age (Offodile & Reyment, 1977). It comprises of a limited band of fine to medium-grain, moderately cemented sandstone known as the Agbani Sandstone and the Akpoha Sandstone (Petters 1978; Agagu &Adighije, 1983; Ojoh, 1990). In the Northern Benue Trough, the Turonian-Coniacian depositional cycle includes the transitional marine Yolde Formations, as well as the marine Pindiga Formations, which reflect the aulacogens' downwarping stage (Obaje, 2009; Abubakar et al., 2010; Aminu et al., 2017; Ogunmola et al., 2020; Adebayo et al., 2022). The Turonian-Coniacian depositional cycle was terminated by a phase of deformation and compressional folding that was evidently developed during the Santonian. Intense and widespread anticlines and synclines, such as the Abakaliki anticlinorium, were the outcome of this event (Burke et al., 1972). The Nkporo Shale consists of Campanian sediments that unconformably overlie the Awgu Formation. The stratigraphic succession of the Southern Benue Trough is depicted in Fig. 1.

The Nkporo Shales is characterized by carbonaceous sediments and unconformably overlain by sandstone, carbonaceous shales, sandy shales and local coal seams which, together form the Mamu Formation (Cratchley & Jones, 1965; Kogbe, 1981) of the Anambra Basin.The Mamu Formation is about 400 m thick and is overlain by 330 m of coarse-grained, typically current-bedded sandstones known as the Ajali Formation (Offodile, 1976). Above the Ajali Formation, a thin layer of what is generally regarded as the most recent sediments of the Southern Benue area was deposited; the Nsukka

Formation which is composed of carbonaceous shales, sandstones, and coal seams. It dates from the Late Maastrichtian to the Early Palaeocene.

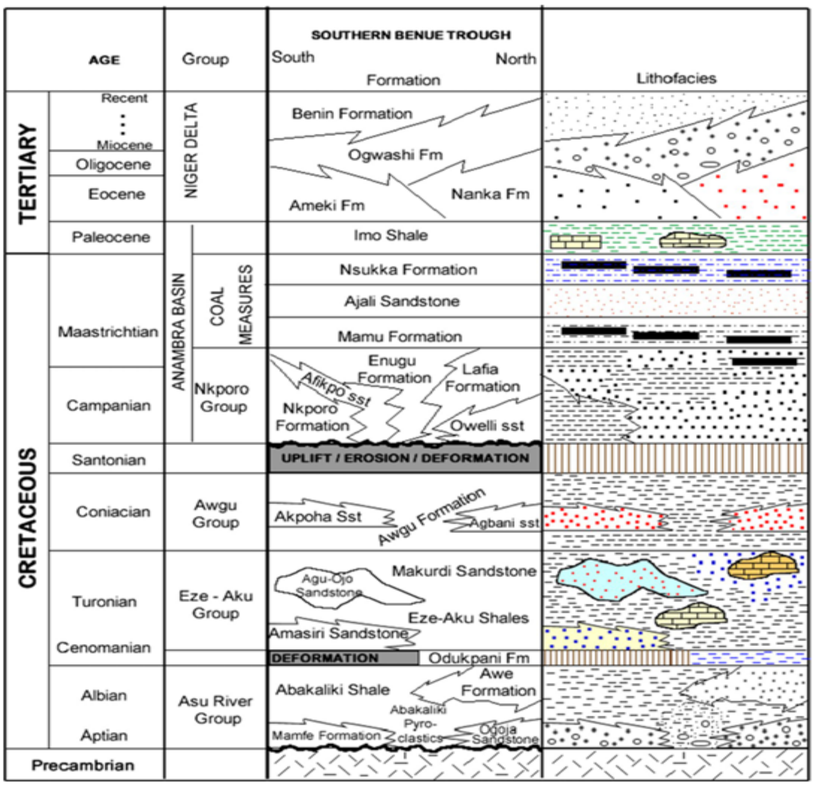

Fig 1: Stratigraphy of the Southern Benue Trough showing the lithofacies successions and distribution of lateral equivalents from the northern reaches of the basin southwards (Modified after Ibe & Okon, 2021)

Rock samples investigated in this study were collected from outcrops of the Asu River Group and the Amasiri Sandstone Member. of the Eze-Aku Group within the Southern Benue Trough (Fig. 2). The rock sequence of the Asu River Group consists of sandstones and mudstones, while the Amasiri Sandstone is composed of shale, calcareous shale and sandstone (Ekwueme et al., 1995). The study area lies between latitudes 5°57′21″N and 6°30′39″N and longitude 7°47′55″E and 8°22′52″E.

2.0 Methodology

Bulk samples of the calcareous sandstones were collected from the field and were subjected to petrography (thin section), physical, and mechanical tests. The rock's of mineralogy and texture were examined by preparing thin sections, examining them under a polarizing microscope.The modal composition was analyzed by studying the photomicrographs with ImageJ (ImajeJ, 2008).

The present study focuses on calcareous sandstones belonging to the Asu River Group and the Amasiri Sandstone Member of the Eze-Aku Group, both of which are widely exposed within the southeastern segment of the Southern Benue Trough. These units constitute important sources of construction materials in the region and therefore warrant detailed petrographic and geomechanical evaluation.

The study area is characterized by extensive exposures of calcareous sandstones that exhibit variations in texture, mineralogical composition, and degree of cementation. These variations are expected to influence their engineering behaviour and aggregate quality, thereby providing an appropriate geological setting for investigating the relationship between petrographic and geomechanical properties.

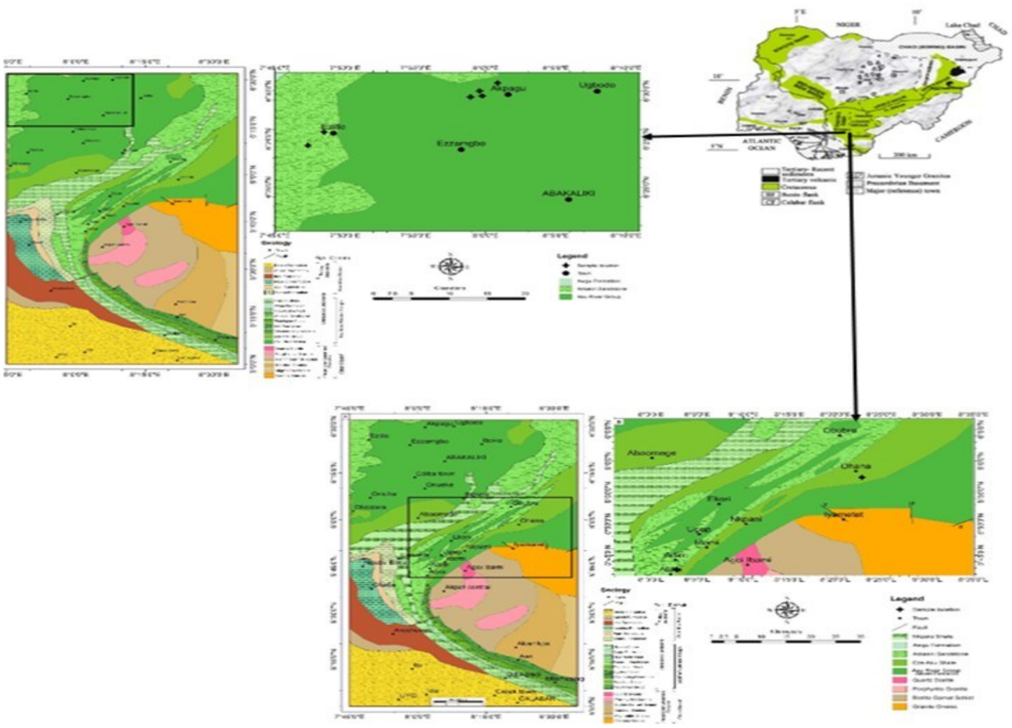

Fig. 2: Geological map of parts of southeastern Nigeria showing the study area

The dry density (ρdry) and porosity were evaluated using the Archimedes method and saturation technique (ISRM, 1979). A weigh balance with an accuracy of 0.01 was used toestimate the dry weight (after oven drying at 110ºC for 24 hours and 30 minutes of cooling) and the saturated surface dry mass (after 24hours of immersion inwater)of the sample. The sample's dry weight was divided by the sample volume to get the unit volume weight of each aggregate. The weight difference between the sample's dry weight and its saturated surface dry weight was used to compute the sample's water absorption as a percentage of its dry weight. The effective porosity value was derived as the ratio of the pore volume to the bulk volume of the sample. The pore volume of the sample was estimated using the weight difference between the saturated weight (surface dry) and the dry sample weight. Bulk density (ρbulk), dry density (ρdry), saturated density (ρsat), specific gravity (G_S), porosity (n), and water absorption capacity (WAC) were calculated using the following relation in Eqn. 1-6:

$$\rho bulk = Mb/V \quad (1)$$

$$\rho dry = Ms/V \quad (2)$$

$$\rho sat = Msat/V \quad (3)$$

$$G_S = \frac{Ms}{Msat - Msw} \quad (4)$$

$$n = (Msat - Ms)/\rho w/V * 100\ \% \quad (5)$$

$$WAC = (Msat - Ms)/Ms * 100\ \% \quad (6)$$

where M_s is the solid mass of the specimen, M_{sat} is the surface-dry saturated mass, Msw is the mass of solid in water, M_b is the bulk mass of the specimen, V is the bulk volume andρ_w is the density of water.

Cylindrical core samples with a diameter of 40mm were prepared and used for the determination of the mechanical properties of the rocks. During the unconfined compressive strength (UCS) test, a length-to-diameter ratio of 2.5:1 was maintained. The core samples were taken using a core drilling machine, and each sample was examined to make sure it was free of macroscopic defects and weathering. Additionally, to ensure accuracy due to instrumental drift, each test as carried out in triplicate for each particular property and the average value of the measured results was then set to represent the UCS of each sample.

For the aggregate degradation test, a jaw crusher was used to produce the irregular samples. The LAAV test was performed following the method prescribed by ASTM-C131 (2006). Aggregate Grade B was employed because it was similar in size to the aggregate used for ACV and AIV. Each sample had an aggregate mass of 5000 ± 10g. The LAAV was estimated as a percentage of the original mass of the tested sample after 500 revolutions using Eqn. 7 below:

$$LAAV = \frac{\text{Initial mass} - \text{Final mass (after 500 revolutions)}}{\text{Initial mass}} * 100\% \quad (7)$$

In the AIV test, a hammer with a mass of approximately 14kg (13.5–14kg) is dropped 15 times from a height of approximately 381mm (381±6.5mm) in accordance with (BS, 1990a). Continuous loading was applied progressively in the ACV test until a total load of about 40 tons was reached in 10 minutes (BS, 1990b).

The AIV or ACV value represents the mass of fine material that passes through the #8 (2.36 mm) sieve as a percentage of the sample's initial weight. It is calculated using equation 8

$$\text{ACV or AIV} = \frac{A - B}{A} * 100\% \quad (8)$$

where A represent the initial mass of rock aggregates, and B represents the final mass remaining on the #8 sieve after impact load for AIV test or crushing load for ACV test.

Slake durability testing was standardized according to (ASTM, 2013). The slake durability test consists of placing an oven-dried sample, consisting of 10–12 pieces, each weighing 40–60g with a total weight of about 450–500g, in a 2 mm-meshed drum and rotating the drum through water for 10min at a fixed speed. The sample that remains in the drum was oven-dried and weighed. The slake durability index (I_d) is computed as the weight of the remaining sample divided by the initial weight multiplied by 100. To determine the second-cycle slake durability index (I_{d2}), the test was repeated on the remaining sample.

3.0 Results and Discussions

3.1.1 Petrographic Analysis

The modal composition of the examined samples is presented in Table 1, while the photomicrographs are shown in Fig. 3a–f. The framework composition reveals that the quartz content ranges from 30 to 68%, feldspar ranges from 2 to 5%, fossil fragments vary from 8 to 32%, opaque mineral ranges from 1% to 2%, and matrix (micrite) ranges from 10% to 38% (Table 1). Quartz was found to be the dominating mineral in all of the studied samples and it occurs mostly as monocrystalline quartz grains. The predominance of quartz suggests a relatively mature sediment source and is expected to contribute positively to the strength and abrasion resistance of the studied rocks because quartz is mechanically stable and highly resistant to weathering and deformation.

The fabric of the calcareous sandstones from Ezillo, Abini, and Akpegu 1 appeared matrix supported, as shown in the photomicrographs. The micritic matrix separates and floats the quartz and plagioclase grains from one another. The occurrence of abundant micrite may be partly attributed to the disintegration of carbonate skeletal materials and fossil fragments during deposition and subsequent diagenesis. The grains are mostly fine to medium grained, but coarser grain sizes were found in the Abini samples.

Table 1: Modal composition of the studied calcareous sandstones in parts of the Southern Benue Trough

Sample	Location	Quartz (%)	Feldspar (%)	Sparite (%)	Micrite (%)	Fossil Fragment (%)	Opaque (%)
Calcareous sandstone	Ezillo	45	4	_	25	25	1
Calcareous sandstone	Abini	30	4	_	38	27	1

Calcareous sandstone	Akpegu 1	30	2	8	27	32	2
Calcareous sandstone	Akpegu 2	68	5	_	17	8	2
Calcareous sandstone	Ngbo 1	64	4	_	13	18	1
Calcareous sandstone	Ngbo 2	65	3	_	10	20	2

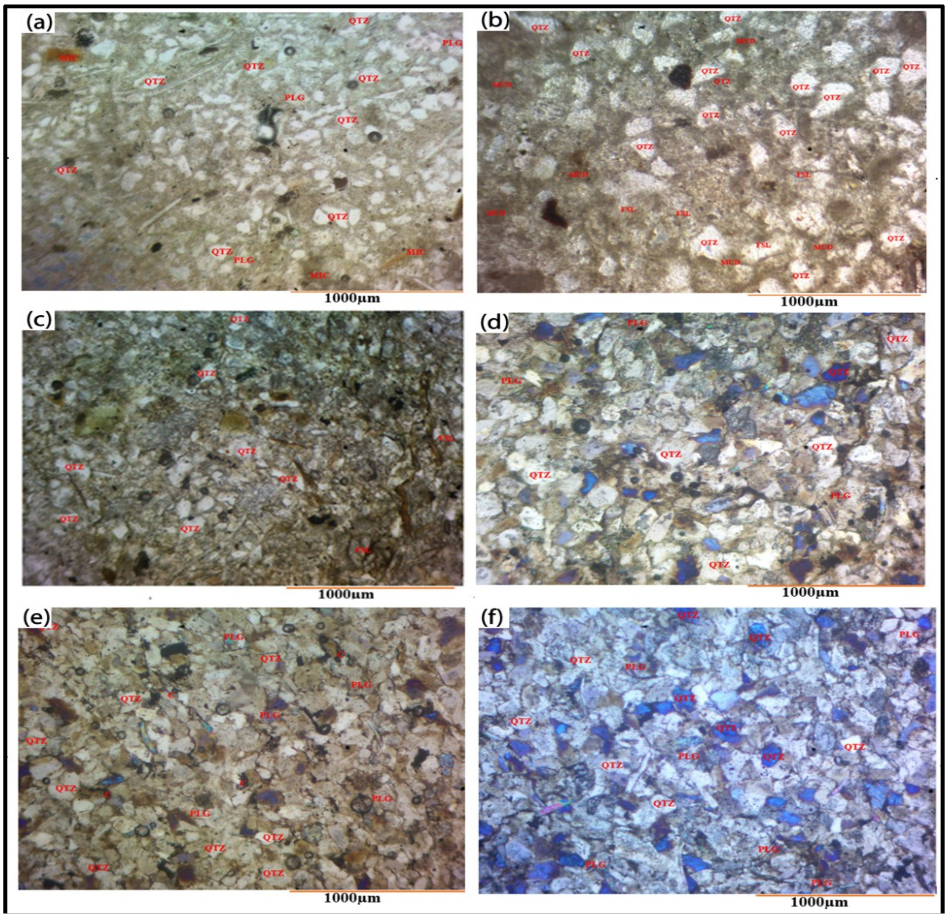

Fig. 3:(a) Photomicrograph of Ezillo calcareous sandstone under plane polarized light; (b) Photomicrograph of Abini calcareous sandstone under plane polarized light; (c) Photomicrograph of Akpegu 1 calcareous sandstone under plane polarized light; (d) Photomicrograph of Akpegu 2 calcareous sandstone under crossed polarized light (e) Photomicrograph of Ngbo 1 calcareous sandstone under crossed polarized light (f) Photomicrograph of Ngbo 2 calcareous sandstone under crossed polarized light

Meanwhile, photomicrographs of calcareous sandstones from Ngbo 1, Ngbo 2 and Akpegu 2 revealed that the samples fabrics are clast-supported. The samples are characterized by low micrite content, close grain packing, and well-developed carbonate cement within the intergranular pores. The grain sizes observed in the samples are fine to medium-grained.

3.1.2 Physical Properties

The result of the test for physical of the sandstones is presented in Table 2. The result shows that the specific gravity for the sandstones range from 2.36 to 2.69g/cm^3. The specific gravity of the calcareous sandstone from Ngbo 1 has the highest value with an average of 2.61g/cm^3 followed by Akpegu 1 and Akpegu 2 with an average of 2.57 g/cm^3 each, Ngbo 2 calcareous sandstone with an average of 2.49g/cm^3, Abini calcareous sandstone with an average of 2.46g/cm^3, and Ezillo calcareous siltstone with an average of 2.36g/cm^3.

The observed variation in density, porosity, and water absorption is largely controlled by differences in grain packing, matrix content, and degree of cementation. Samples characterized by clast-supported fabrics generally exhibit lower porosity and water absorption due to tighter grain packing and more effective pore filling by cementing materials. In contrast, matrix-supported samples contain higher proportions of micrite and exhibit relatively higher pore volumes, resulting in greater water absorption capacity.

Table 2: Physical properties of calcareous sandstones from parts of Southern Benue Trough

Sample	Location	Specific Gravity	Dry Density (g/cm^3)	Porosity (%)	WA (%)
Calcareous Sandstone	AKPEGU 2	2.57	2.50	5.20	2.10
Calcareous Sandstone	NGBO 1	2.61	2.53	3.20	1.30
Calcareous Sandstone	NGBO 2	2.49	2.54	5.70	2.30
Calcareous Sandstone	AKPEGU 1	2.57	2.55	5.00	2.00
Calcareous Sandstone	ABINI	2.46	2.39	7.10	3.00
Calcareous Siltstone	EZILLO	2.36	2.31	11.80	5.10

The dry density values range between 2.31g/cm^3 (Ezillo calcareous siltstone) and 2.55g/cm^3 (Akpegu 1 calcareous sandstone). According to (IQS, 1989), the calcareous sandstones are classified as having medium dry density (Fig. 4). This range falls within the typical density category for aggregates (NF, 1983). The porosity and water absorption (WA) values varied from 3.2 to 11.8% and 1.3 to 5.1%, respectively. As shown in Fig. 5, the samples from Ngbo 1, Akpegu 1, and Akpegu 2 have the least porosity and are classed as low porosity, whereas the remaining samples are of medium porosity (Blyth & De Freitas, 1974). Ngbo 1 and Akpegu 1 samples likewise exhibit low WAC, with values below 2%. The highest porosity and water absorption values were found in the calcareous sandstones from Abini and Ezillo.

3.1.3 Mechanical properties

The result of mechanical properties of the studied sandstones is presented in Table 3. The aggregate impact value (AIV) of the tested rocks ranged from 15.87% to 22.52% (Table 3). The test provides a relative measure of the resistance of aggregates to sudden shock or impact and granulation or pulverization (Al-Harthi, 2001). The relatively low AIV values obtained for most samples indicate good resistance to impact loading and suggest suitability for use as construction aggregates subjected to dynamic stresses. Higher aggregate resistance during the AIV test is indicated by a numerically lower result. According to (BS, 1990b), AIV should be less than 20%, so only the samples from the Abini and Ezillo study areas fall outside the recommended limits for construction activities. The aggregate crushing value (ACV) test recorded values that ranged from 16.34% to 26.29%. This text presents a relative assessment of an aggregate's resistance to crushing under a gradually applied compressive load.

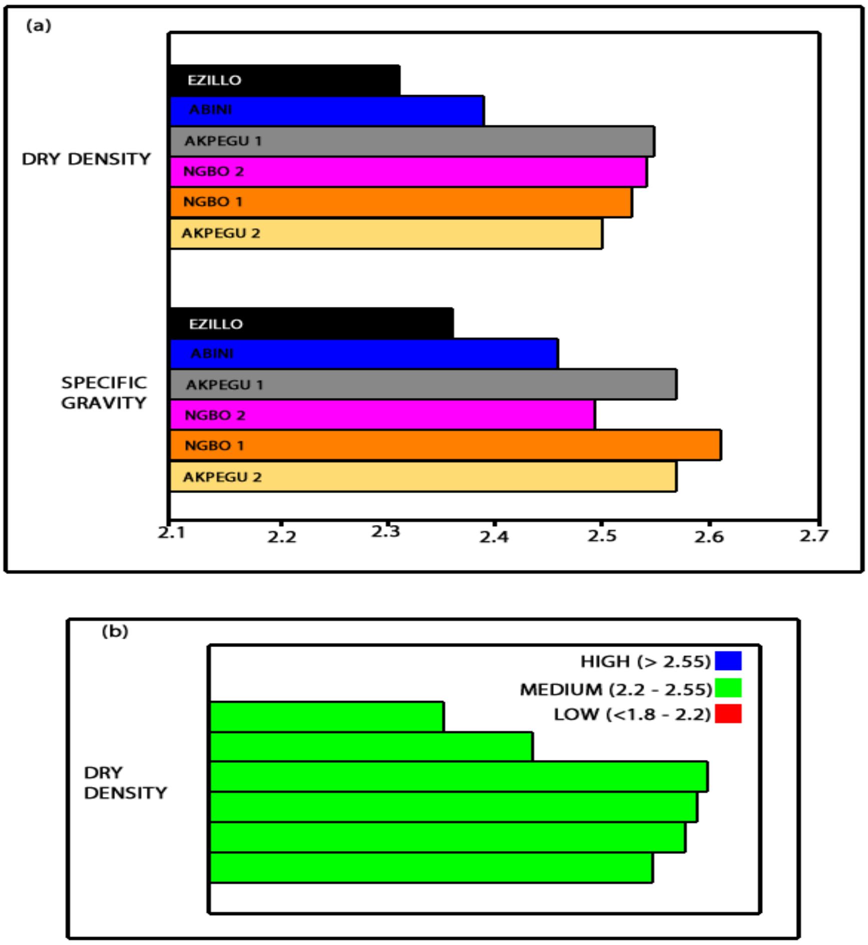

Fig. 4: Dry density and specific gravity properties of the studied samples

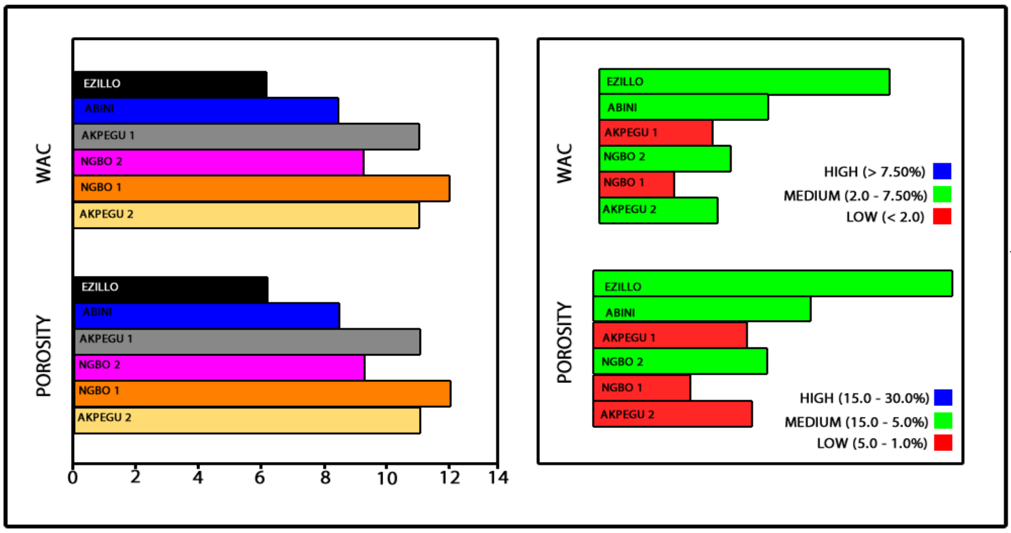

Fig. 5: Porosity and water absorption properties of the studied samples

Therefore, a material with a high crushing value is weak and might not be durable. Thus, the smaller the ACV, the greater the aggregate's ability to withstand crushing. All the samples should function satisfactorily in engineering applications where crushing forces predominate since they fall within the recommended limit of 30% (BS, 1990b).

The Los Angeles abrasion value (LAAV) of the aggregates tested ranged from 38.62 to

53.10 %. The Los Angeles test exposes the materials to both impact and attrition, with the latter likely having a greater effect. Harrison and Bloodworth (1994), state that aggregates with LAAV less than 50% can be used for base course, and aggregates with LAAV less than 40% can be used for wearing course.

The rock samples had unconfined compressive strength (UCS) ranging from 20 to 41 MPa. They have UCS values that fall within the weak and moderately strong classification categories (ISRM, 1981).

The slake durability index ranged from 91.1 obtained in the Akpegu 1 calcareous sandstone to 97.6% recorded in the Akpegu2 calcareous sandstone. The variation in slake durability results is dependent on the deployed test method and the rock sample being studied (Ersoz & Dursun, 2026).The slake durability index test results revealed that Akpegu2 calcareous sandstone, Hasan average value of 97.6 %; Ngbo 1 calcareous sandstone, has an average value of 96.4 %; Ngbo 2 calcareous sandstone, has an average of 96.7 %; Abini calcareous sandstone, has an average of 93.4 %; Ezillo calcareous sandstone, has an average of 91.6 % and Akpegu1 calcareous sandstone, with an average of 91.1 %. The conventional slake durability results suggests that the calcareous sandstones obtained from Akpegu 1, Abini and Ezillo areas are of medium durability while the samples obtained from Akpegu 2, Ngbo 1, Ngbo 2 and are of medium to high durability category according to ISRM, (1981) classification.

Table 3: Mechanical properties of some calcareous sandstones in parts of the Southern Benue Trough

Rock Type	Location	UCS (MPa)	AIV (%)	ACV (%)	LAAV (%)	Slake Durability (%)
Calcareous Sandstone	Akpegu 2	41.0	19.50	16.34	39.36	97.6
Calcareous Sandstone	Ngbo 1	38.0	15.87	16.35	38.62	96.4
Calcareous Sandstone	Ngbo 2	35.0	16.32	17.07	39.64	96.7
Calcareous Sandstone	Akpegu 1	28.0	18.10	20.09	42.70	91.1
Calcareous Sandstone	Abini	24.0	21.86	26.29	53.10	93.4
Calcareous Siltstone	Ezillo	20.0	22.52	23.90	49.28	91.6

****UCS = Uniaxial Compressive Strength; AIV = Aggregate Impact Value; ACV = Aggregate Crushing Value; LAAV = Los Angeles Abrasion Value**

3.2 *Discussions*

3.2.1 Relationship between petrographical properties and mechanical properties

The examined rocks can be grouped into two groups on the basis of their textural properties: matrix-supported and clast-supported rocks. The examined calcareous sandstones with matrix-supported fabric showed low mechanical quality. The results of this study revealed that when these rock groups are subjected to aggregate degradation tests, they produced a notable loss. When subjected to the impact and crushing test, the samples from Ezillo and Abini showed the greatest loss, which exceeded the specified recommended limit of 20% for construction-related activities. The matrix-supported samples similarly lose more than 40% after passing the Los Angeles test. The strength qualities were classified as weak (20 - 28 MPa), with a medium resistance to slaking.

Conversely, samples made of clast-supported fabric had superior mechanical properties. They exhibited moderate strength, high to medium resistance to slaking, and superior resistance to aggregate degradation.

The impact of the mineralogical composition on the mechanical properties of the calcareous sandstone rocks under investigation was estimated using correlation analysis. To determine the mechanical behaviours of the various characteristic from one another, the selected mechanical and petrographic properties were plotted against one another. The scatter plots illustrating the correlation between the mechanical properties and mineral contents of the samples under study are displayed in Fig. s 6 - 8. The unconfined compressive strength and slake durability showed a significant positive correlation with the quartz content (Figs. 6a and 6b), whereas the aggregate degradation (AIV and LAAV) test values showed a significant inverse relationship with the quartz content (Figs. 6c and 6d). Quartz grains possess no cleavage and are highly resistant to abrasion; therefore its abundance in a rock often leads to higher strength, which can boost the rock's resistance to wear and fragmentation. This explains why samples with more quartz had noticeably higher strength, whereas those with less quartz had lower strength and higher aggregate deterioration.

Plotting the micrite concentration against the unconfined compressive strength and slake durability values, however, reveals a notable inverse connection (Fig. 7a). This indicates that the micrite concentration contributes negatively to the strength and durability values observed in the studied rocks. The percentage of micrite and the aggregate degradation metrics also showed a strong positive association (Figs. 7b – 7d). This same pattern emerged when the aggregate degradation parameters were plotted against the total micrite and fossil content (Figs. 8a – 8b). This demonstrates that a rising content of micritic percentage in the tested samples reduces their capacity to resist wear and fragmentation when subjected to impact and crushing stresses. The substantial relationship observed in Fig. 8cb between aggregate crushing value and micrite content indicates that the micrite content present in calcareous sandstones is crucial, especially when considered in engineering applications where crushing forces are significant.

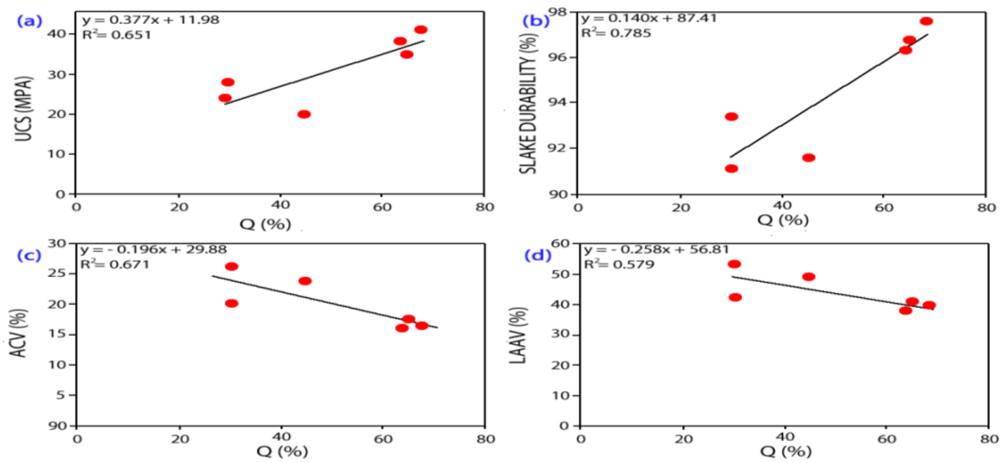

Fig. 6 Relationship between mechanical parameters against quartz (a) UCS vs Quartz; (b) Slake durability vs Quartz; (c) ACV vs Quartz; (d) LAAV vs Quartz

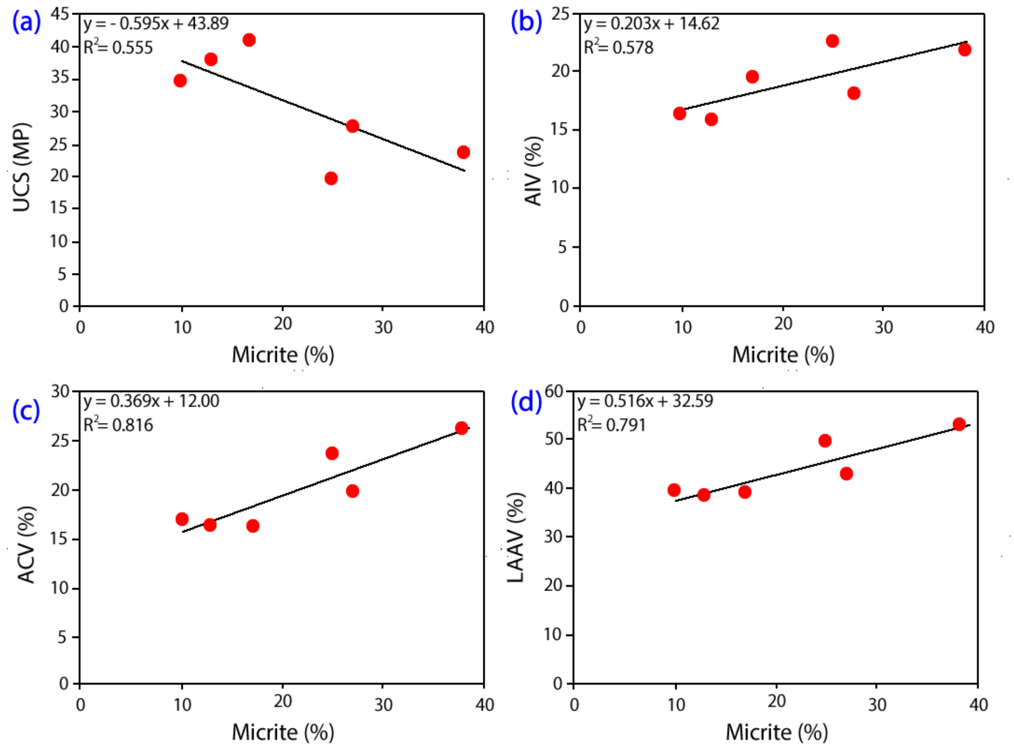

Fig 7: (a) Relationship between UCS and micrite content (b) Relationship between AIV and micrite content (c) Relationship between ACV and micrite content (d) Relationship between LAAV and micrite content

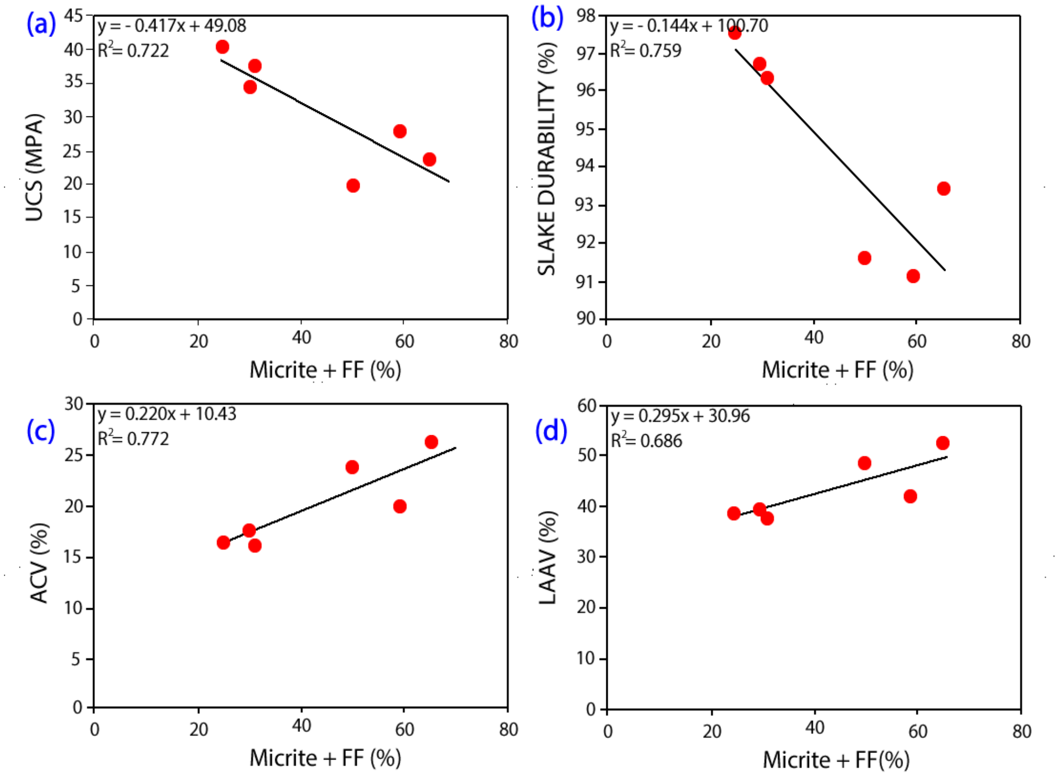

Fig 8: (a) Relationship between UCS and micrite + FF content (b) Relationship between slake durability and micrite + FF content (c) Relationship between ACV and micrite + FF content (d) Relationship between LAAV and micrite + FF content

3.2.2 Relationship between physical and mechanical properties

Additionally, there was a correlation between several physico-mechanical properties. There was a notable positive correlation found between the UCS and slake durability, dry density, and specific gravity.

The correlation between uniaxial compressive strength and the specific gravity (G_S) was significant (r^2 = 0.6306). The relationship is related by Eqn. 9.

UCS = 71.362 G_S – 148.12 (10)

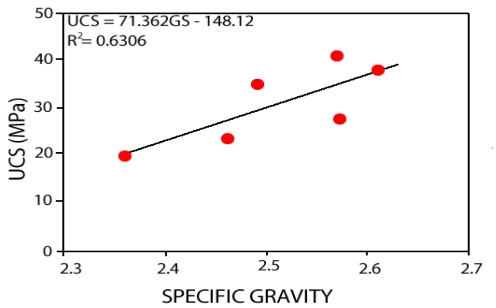

Fig 9: (a) Relationship between UCS and specific gravity

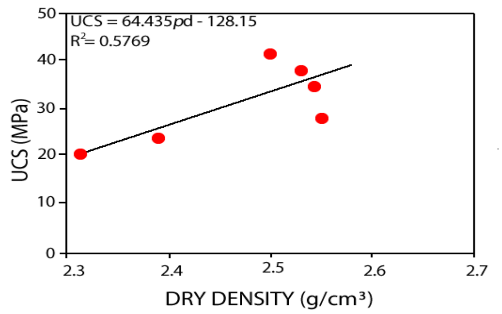

Fig. 9b: Relationship between UCS and dry density

Fig. 9b illustrates the relationship between the dry density (pd) and the uniaxial compressive strength. The Fig. shows that when the dry density increased, UCS increased as well (r^2 = 0.5769). The relating equation between them is presented in Eqn. 10

UCS = 64.435 p_d– 128.15 (10)

The positive relationship between dry density and compressive strength indicates that denser rocks possess fewer void spaces and stronger intergranular contacts, resulting in improved load-bearing capacity. Results of the tests between the UCS and Slake durability index (SD) values showed that there was a good positive linear relationship as shown in Fig. 10 with the following equation:

UCS = 2.6228 S_D– 216.76 (11)

The strong relationship between UCS and slake durability indicates that both parameters are influenced by similar intrinsic characteristics, including cementation, porosity, grain packing, and mineralogical composition. The comparative relationship between the aggregate degradation and the compressive strength was also examined and it showed a significant negative linear relationship between them (Figs 11a-c). The same relationship was noticed when the porosity of the samples was plotted against the compressive strength (Fig 12)

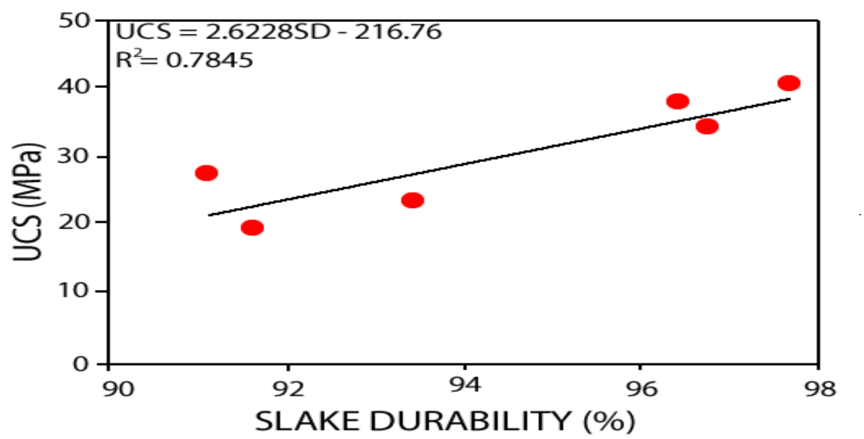

Fig. 10: Plot of UCS against slake durability

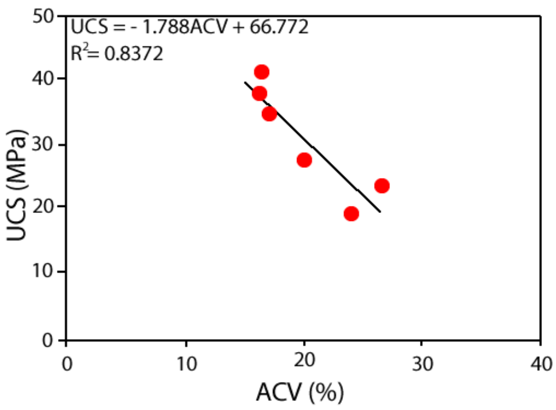

Fig. 11 (a): Relationship between UCS and ACV

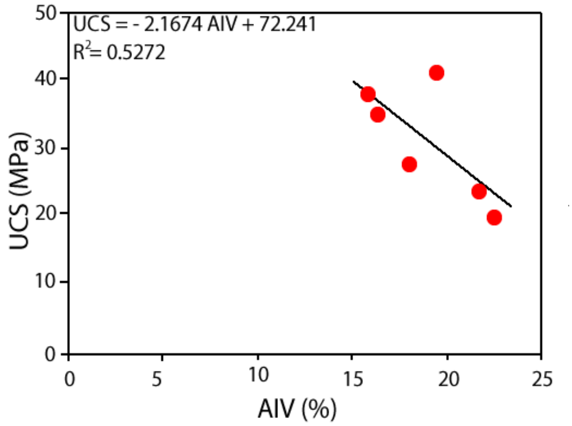

Fig. 11 (b): Relationship between UCS and AIV

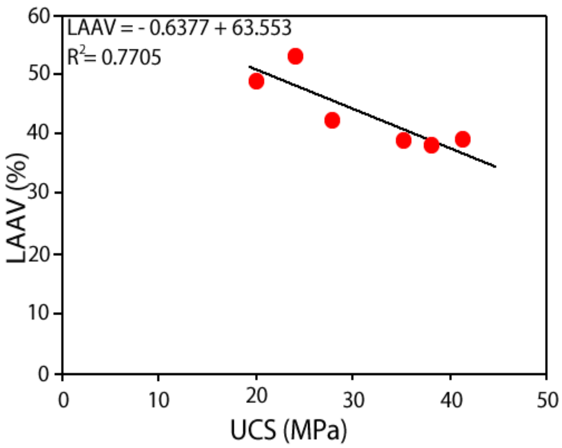

Fig. 11: (c) Relationship between UCS and LAAV

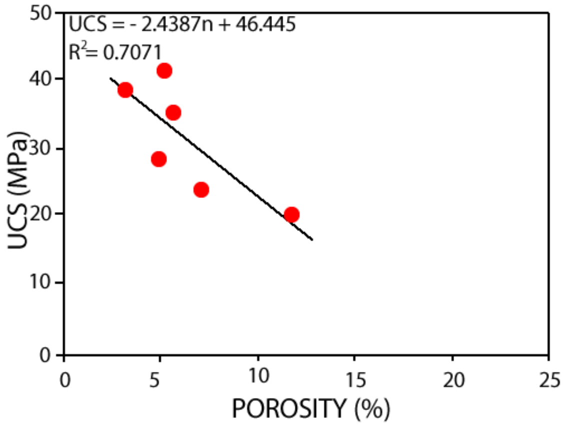

Fig. 12: Relationship between UCS and Porosity

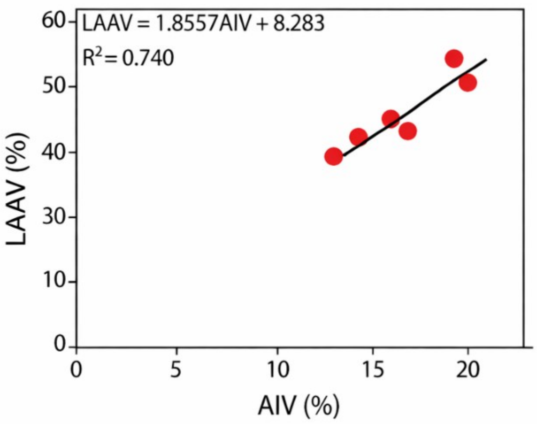

Fig 13a: Relationship between LAAV and AIV

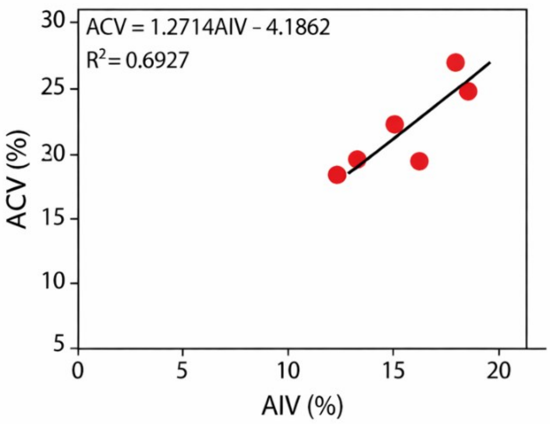

Fig 13b: Relationship between ACV and AIV

A good positive linear correlation was observed between the Los Angeles abrasion, aggregate impact, and aggregate crushing values, according to the test results (Figs 13 a-c). The analysis revealed that the LAAV increased linearly as AIV and ACV increases.

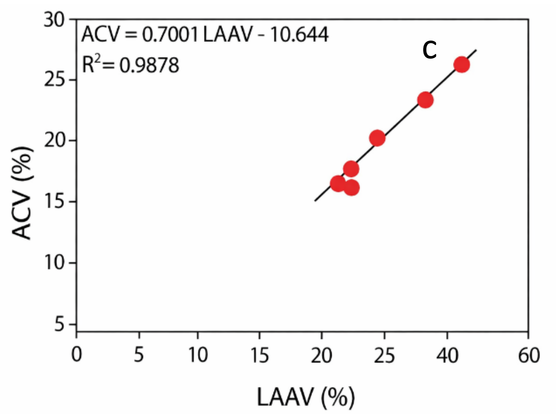

Fig 13c: Relationship between ACV and LAAV

4.0 Conclusion

Regression analysis was used to assess the correlation between petrographic features and physico-mechanical parameters of calcareous sandstones in the southern Benue Trough. The materials analyzed are calcareous sandstones from four different locations. The findings of this study can be stated as follows:

- The petrographic analysis reveals that the quartz content ranges from 30 to 68%, feldspar ranges from 2 to 5%, fossil fragments vary from 8 to 32%, opaque mineral ranges from 1 to 2%, and matrix (micrite) ranges from 10 to 38%. Additionally, the samples from Ezillo, Abini, and Akpegu 1 were matrix-supported, as revealed by the photomicrographs, while those from Ngbo 1, Ngbo 2, and Akpegu 2 samples are clast-supported.
- The rock's strength falls within the weak and moderately strong classification categories. The aggregate degradation properties were within the recommended limit apart from those from the Abini and Ezillo areas.
- The examined calcareous sandstones with matrix-supported fabric showed low quality and it was observed that they yielded a notable aggregate degradation loss. Conversely, samples made of clast-supported fabric had superior mechanical properties.
- The unconfined compressive strength and slake durability index showed a significant positive correlation with the quartz content, whereas the aggregate degradation (AIV and LAA) test values showed a significant inverse relationship with the quartz content. Notable inverse connections were observed between the micrite concentration and the unconfined compressive strength and slake durability values. An increase in the percentage of micrite in the tested samples reduced their capacity to resist wear and fragmentation when subjected to impact and crushing stresses.
- The substantial relationship between aggregate crushing value and micrite content indicates that the amount of micrite present in a rock is crucial, especially in applications where crushing forces are significant.
- Conclusively, the mineralogical components significantly impact the strength, LAAV, ACV and slake durability index of the studied rocks.

Overall, the study demonstrates that petrographic characteristics, particularly mineralogical composition and fabric type, exert a strong control on the physico-mechanical behaviour of calcareous sandstones in the Southern Benue Trough. These findings highlight the importance of petrographic analysis as a reliable tool for predicting aggregate performance in engineering applications.

5.0 References

Abubakar, Y. I., Umegu, M. N., & Ojo, S. B. (2010). Evolution of Gongola Basin Upper Benue Trough Northeastern Nigeria. *Asian Journal of Earth Sciences*, 3, pp. 62–72.

Adebayo, K. I., Oyetade, O. P., & Kudamnya, E. A. (2022). Geotechnical and mineralogical assessment of Gerinya clays within the Patti Formation, Southern Bida Basin, Nigeria. *Pakistan Journal of Geology*, 6, 2, pp. 40–46.

Ademeso, O. A. (2024). The significance of petrography in characterizing the UCS of crystalline rocks and verifying the applicability for economic purposes. In O. J. Ojo (Ed.), *Probing into the Precambrian banded iron formations and other minerals of Nigeria* (pp. 49–56). Cresolint Global Resources.

Adighije, C. (1981). Gravity study of Lower Benue Trough. *Geological Magazine*, 181, 1, pp. 59–67.

Agagu, O. K., & Adighije, C. I. (1983). Tectonic and sedimentation framework of the Lower Benue Trough, southeastern Nigeria. *Journal of African Earth Sciences*, 1, pp. 267–274. https://doi.org /10.1016/S0731-7247(83)80011-1

Al-Harthi, A. A. (2001). A field index to determine the strength characteristics of crushed aggregate. *Bulletin of Engineering Geology and the Environment*, 60, pp. 193–200.

Aminu, M. D., Ardo, B. U., & Jato, M. A. (2017). A bibliography of geological studies on the Benue Trough of Nigeria: 2000–2015. *RAPSCI Mini Review*. https://doi.org/10.19080/RAPSCI.2017.03.555612

ASTM C131/C131M-14. (2006). *Standard test method for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles machine*. ASTM International.

ASTM (American Society for Testing and Materials). (2013). *Annual book of ASTM standards: Soil and rock (Section 4.08, Vol. 4)*. ASTM International.

Blyth, F. G. H., & De Freitas, M. H. (1974). *A geology for engineers*. ELBS/Arnold.

BS (British Standards Institution). (1990a). *Testing aggregates, BS 812 Part 112: Methods for determination of aggregate impact value (AIV)*. British Standards Institution.

BS (British Standards Institution). (1990b). *Testing aggregates, BS 812 Part 110: Methods for determination of aggregate crushing value (ACV)*. British Standards Institution.

Burke, K. C., Dessauvagie, T. F. J., & Whiteman, A. J. (1972). Geological history of the Benue Valley and adjacent areas. In K. C. Burke & T. F. J. Dessauvagie (Eds.), *Proceedings of the Conference on African Geology* (pp. 187–200). University of Ibadan Press.

Cratchley, C. R., & Jones, G. P. (1965). *An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria*. Geophysical Paper No. 1, Overseas Geological Survey.

Edet, A. E. (1992). Physical properties and indirect estimation of microfractures using Nigerian carbonate rocks as examples. *Engineering Geology*, 33, pp. 71–80.

Edet, A. E. (2018). Correlation between physio-mechanical parameters and geotechnical evaluations of some sandstones along the Calabar/Odukpani–Ikom–Ogoja Highway Transect, southeastern Nigeria. *Geotechnical and Geological Engineering*, 36, pp. 135–149. https://doi.org/10.1007/s10706-017-0311-z

Ekwueme, B. N., Nyong, E. E., & Petters, S. W. (1995). *Geological excursion guidebook to Oban Massif, Calabar Flank and Mamfe Embayment, Southeastern Nigeria*. Decford Publishers.

Harrison, D. J., & Bloodworth, A. J. (1994). *Industrial minerals laboratory manual: Construction materials* (Technical Report WG/94/12). British Geological Survey.

Ibe, C. U., & Okon, E. E. (2021). Provenance and tectonic settings of the Eze-Aku Sandstone (Turonian) in Awajir and adjoining areas, Southern Benue Trough, Nigeria: Evidence from petrography and geochemistry. *Journal of Sedimentary Environments*, 6, pp. 237–254. https://doi .org/10.1007/s43217-021-00054-7

IQS (Iraqi Standards). (1989). *Natural building stone* (IS No. 1387). Iraqi Standards Organization.

Irfan, T. Y. (1996). Mineralogy, fabric properties and classification of weathered granites in Hong Kong. *Quarterly Journal of Engineering Geology and Hydrogeology*, 29, pp. 5–35.

Ismail, N. R., & Abdulwahid, M. Y. (2021). Engineering characterization of local limestone and marlstone aggregates in Koya Area as a case study. *Journal of Materials and Engineering Structures*, 8, pp. 269–278.

ISRM (International Society for Rock Mechanics). (1979). Commission on standardization of laboratory and field tests: Suggested methods for determining water content, porosity, density, absorption and related properties and swelling and slake durability properties. *International Journal of Rock Mechanics and Mining Sciences*, 16, pp. 148–156.

ISRM. (1981). Commission on the Classification of Rocks and Rock Masses: Basic geotechnical description of rock masses. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, 18, pp. 85–110.

Kanji, M. A. (2014). Critical issues in soft rocks. *Journal of Rock Mechanics and Geotechnical Engineering*, 6, pp. 186–195.

Kamani, M., & Ajalloeian, R. (2018). Evaluation of the mechanical degradation of carbonate aggregate by rock strength tests. *Journal of Rock Mechanics and Geotechnical Engineering*, 11, pp. 121–134. https://doi.org/10.1016/j.jrmge.2018.05.007

Kamran, A., Ali, L., Ahmed, W., Zoreen, S., Johan, S., Janjuhah, H. T., Vasilatos, C., & Kontakiotis, G. (2022). Aggregate evaluation and geochemical investigation of limestone for construction industries in Pakistan: An approach for sustainable economic development. *Sustainability*, 14, 17, pp. 1–45.

Kogbe, C. A. (1981). Attempt to correlate the stratigraphic sequence in the Middle Benue Basin with those of the Anambra and Upper Benue Basins. *Earth Evolution Sciences*, 1, pp. 139–143.

Kudamnya, E. A., Nyong, V. E., Adebayo, I. K., Okon, E. E., Oko, A. A., Joshua, G. I., Asuquo, H. I., Osumeje, J. O., Irek, F. P., Edet, A. E., Nganje, T. N., Adamu, C. I., Ekwere, A. S., & Kave, G. T. (2026). A multi-criteria decision using analytical hierarchy process (AHP) for delineation of groundwater potential zones in part of the Obudu Massif, Nigeria. *Communications in Physical Sciences*, 13, 5. (In Press).

Makani, A. (2014). Analytical estimate of the mechanical behaviour of rock: Granitic aggregates. *Arabian Journal of Science and Engineering*, 39, pp. 3651–3663. https://doi.org/10.1007/s13369-014-1072-0

NF(L'Association Française de Normalisation). (1983). *Granulats: Vocabulaire, définitions, classification* (NF P18-101). Association Française de Normalisation.

Nwimo, C. E., Ohaegbulem, M. C., Aghamelu, O. P., Iloanya, N. S., & Nwachukwu, C. M. (2021). Preliminary investigation on the quality of Amasiri sandstone (Southeastern Nigeria) as construction material. *Journal of Geology and Mining Research*, 13, 2, pp. 21–30. https://doi.org/10.5897/JGMR2019.0312

Obaje, N. G. (2009). *Geology and mineral resources of Nigeria*. Lecture Notes in Earth Sciences, Vol. 120. Springer. https://doi.org/10.1007/978-3-540-92685-6_5

Offodile, M. E. (1976). The geology of the Middle Benue, Nigeria. *Cretaceous Research*, 1, pp. 101–124.

Offodile, M. E., & Reyment, R. A. (1977). Stratigraphy of the Keana–Awe area of the Middle Benue region of Nigeria. *Bulletin of* *the Geological Institutions of the University of Uppsala*, 7, pp. 37–66.

Ogunmola, J., Ayolabi, E., & Olobaniyi, S. (2020). Structural interpretation and tectonic evolution of the Upper Benue Trough using high-resolution aeromagnetic data and satellite imagery. In *SEG Annual Meeting Proceedings*. https://doi.org/10.1190/ segam2020-3400300.1

Ojoh, K. A. (1990). Cretaceous geodynamic evolution of the southern part of the Benue Trough (Nigeria) in the equatorial domain of the South Atlantic: Stratigraphy, basin analysis and paleoceanography. *Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine*, 14, 2, pp. 419–442.

Ojong, R. A., Okon, E. E., & Mode, A. W. (2018). Impact of texture and diagenesis on reservoir quality of some Pre-Santonian sandstones (Asu River Group and Eze-Aku Formation), Southern Benue Trough, Nigeria. *Asian Journal of Geological Research*, 1, 3, pp. 1–16. https://doi.org/10.9734/AJOGER/2018/46176

Okon, E. E., Essien, N. U., Oyetade, O. P., Kudamnya, E. A., Otele, A., & Ikporukpo, B. (2023). Sandstone petrography and geochemistry of the Pre-Albian Awi Formation, Calabar Flank, Southeast Nigeria. In A. Çiner, S. Banerjee, F. Lucci, A. E. Radwan, A. A. Shah, D. M. Doronzo, Z. Hamimi, & W. Bauer (Eds.), *Recent research on sedimentology, stratigraphy, paleontology, tectonics, geochemistry, volcanology and petroleum geology* (pp. 91–94). Advances in Science, Technology & Innovation. https://doi. /10.1007/ 978-3-031-43222-4_20

Okon, E. E., Ojong, R. A., & Chikezie, C. P. (2026a). Sedimentological attributes of some Pre-Santonian sandstones in parts of the Abakaliki Sub-Basin of the Southern Benue Trough, Nigeria: Evidence from textural analysis and diagenetic imprints. *Global Journal of Geological Sciences*, 24, 2.

Okon, E. E., Kudamnya, E. A., Essien, N. U., Inyang, D. O., Nton, M. E., & Ugbaja, A. N. (2026b). Sedimentological studies of the conglomerate facies of the Awi Formation, Calabar Flank, Southeast Nigeria: Implications for paleoenvironments and economic geology. *Global Journal of Geological Sciences*, 24, pp. 77–85.

Petters, S. W. (1978). Stratigraphic evolution of the Benue Trough and its implications for the Upper Cretaceous paleogeography of West Africa. *Journal of Geology*, 86, pp. 311–322.

Petters, S. W., Okereke, C. S., & Nwajide, C. S. (1987). Geology of the Mamfe Rift, southeastern Nigeria. In G. Matheis & H. Schandelmeier (Eds.), *Current research in African earth sciences* (pp. 299–302). Balkema.

Pomonis, P., Rigopoulos, I., Tsikouras, B., & Hatzipanagiotou, K. (2007). Relationships between petrographic and physico-mechanical properties of basic igneous rocks from the Pindos ophiolitic complex, NW Greece. In *Proceedings of the 11th International Congress of the Geological Society of Greece*, (pp. 947–958), doi:10.12681/bgsg.16778

Rodrigues, J. D. (1988). Proposed geotechnical classification of carbonate rocks based on Portuguese and Algerian examples. *Engineering Geology*, 25, pp. 33–43.

Tamrakar, N. K., Yokota, S., & Shrestha, S. D. (2007). Relationships among mechanical, physical and petrographic properties of Siwalik sandstones, Central Nepal Sub-Himalayas. *Engineering Geology*, 90, pp. 105–123.

Teme, S. C. (1991). An evaluation of the engineering properties of some Nigerian limestones as construction materials for highway pavements. *Engineering Geology*, 31, pp. 315–326.

Uzuakpunwa, A. B. (1974). The Abakaliki pyroclastics, Eastern Nigeria: New age and tectonic implication. *Geological Magazine*, 111, pp. 65–70.

Yasir, S. F., Awang, H., & Ayub, M. I. H. (2018). The relationship of sandstone strength with mineral content and petrographic characteristics in Sungai Tekai, Jerantut, Pahang. In *Proceedings of the AIP Conference on Advances in Civil Engineering and Science Technology* (pp. 020010-1–020010-7). https://doi.org/10.1063/ 1.5062636

Yusof, N. Q. A. M., & Zabidi, H. (2016). Correlation of mineralogical and textural characteristics with engineering properties of granitic rock from Hulu Langat, Selangor. In *Proceedings of the 5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) and 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP)* (pp. 975–980).

Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

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Authors' contributions

Emmanuel Etim Okon conceived the study, coordinated fieldwork, analysed data and prepared the manuscript. Kehinde Ibrahim Adebayo, Ebenezer Agayina Kudamnya and Andrew Sunday Oji contributed to sampling, laboratory analyses and interpretation. Victor Etim Nyong participated in petrographic studies and data validation. Muhideen Alade Saliu contributed to geomechanical evaluation and statistical analyses. Odunyemi Anthony Ademeso supervised the research, reviewed results and critically revised the manuscript. All authors approved the final version.