

Geomechanical Properties and Engineering Suitability of Crystalline Rock Aggregates: A Study of Selected Lithologies from the Oban Massif, Southeastern Nigeria

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Abstract

In Nigeria and throughout the world, there is an enormous need for new infrastructure due to population expansion and development, which is growing in geometric progression. However, in contrast to conventional engineering materials, the geo-materials utilised for building and foundations include inherent flaws such joints, cracks, and mineral alignments that may affect both construction safety and structural performance. The material's petrography, or physical and chemical composition, is closely related to these crucial behaviours. In order to ascertain if 36 crystalline rock samples from southeast Nigeria, including granite, basalt, and amphibolite, were suitable for civil engineering construction, this research assessed their geo-mechanical characteristics.

The samples' Specific Gravity (SG) of 2.55-2.98, density of 2.47-2.70 g/cm³, and low Water Absorption Capacity (WAC) of 0.22-0.86% indicate low porosity and strong durability, according to the evaluation's findings regarding physical and engineering parameters. Aggregate Crushing Values (ACV) of 15.6-20.7%, Aggregate Impact Values (AIV) of 10.3-20.85%, Los Angeles Abrasion Values (LAAB) of 20.9-24%, and Uniaxial Compressive Strength (UCS) ranging from 112 to 189 MPa are all indicative of high, competent strength for building materials, according to laboratory tensile strength tests conducted in accordance with both ASTM and BS standards.

These findings imply that these crystalline rocks are often high-quality materials appropriate for a range of civil engineering uses, including the building of roads, the manufacture of concrete, and structural foundations. Additionally, employing geo materials with a high dependency ratio and flawless quality control will ensure a high Factor of Safety (FoS), facilitate engineering design, lower the number of fatal incidents resulting from failed structures, increase longevity, and guarantee infrastructure sustainability.

Keywords: *Rock strength evaluation techniques, Mechanical properties, Quartz-feldspar ratio (QFR), Aggregate performance, Uniaxial Compressive Strength (UCS), Rock durability, Water Absorption Capacity (WAC), Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), Engineering materials characterization.*

Date of Submission: 12-05-2026

Date of Acceptance: 26-05-2026

I. INTRODUCTION

The engineering performance of building and foundation materials is closely linked to their mechanical and physical characteristics. By examining their geo-mechanical characteristics, this research seeks to determine if crystalline basement rocks from Southeast Nigeria are suitable for engineering building. To ascertain if these rocks satisfy building requirements, the study evaluates characteristics such specific gravity, moisture content, compressive strength, and abrasion resistance.

The need for basic utilities like food, housing, and roads has grown due to Nigeria's fast population growth, which has also raised the requirement for crushed rock material in the form of aggregate required for civil construction (Amah et al., 2012). As a result, investors have established a number of quarries to produce rock aggregates. The goal of these quarried rocks is to provide reasonably priced aggregates for civil engineering applications. However, because to rising energy and production costs, the price of the aggregates from these regions has been rising recently. Growing populations, housing shortages, and growing living standards that require better infrastructure are driving up demand for geo-materials in civil engineering projects. They are crucial for safe, contemporary building and foundation work since they were among the first raw materials used.

This study is important for selecting suitable rock materials for engineering applications by evaluating key properties such as moisture content, specific gravity, and water absorption capacity. It highlights the need to understand material behavior under different conditions, as rocks are widely used in construction and soil

formation. Proper evaluation of these geo-materials can reduce costs, improve safety, support sustainability, and enhance the reliability of engineering designs.

Because the quality of geo-materials required for engineering construction varies by location, it is necessary to assess, characterize, and offer these materials for usage to increase the infrastructure's service life. However, since it also includes a material's longevity in construction, serviceability is a more complicated functional feature.

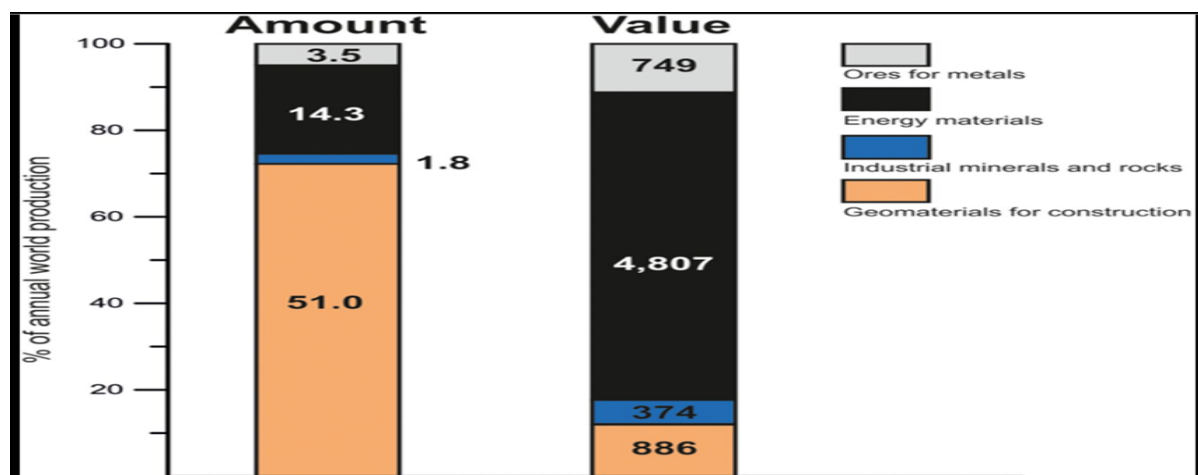


Figure 1: Relative ratios of the quantity and value of raw materials that have recently been removed from the Earth (based mostly on data for 2017). For every category of mineral raw materials on display, including ores for metals, industrial minerals and rocks, energetic raw materials (fossil fuels plus uranium), and building materials, the absolute figures (in billions of tonnes (Gt (Gigatonnes) and in billions of US dollars) are also presented. (Source: Geological Society, London, Special Publications (2016), Volume 416, Sustainability of geo-materials for building.

Infrastructure safety depends not only on sound technical design but also on other critical factors such as material quality, construction practices, environmental conditions, and maintenance. Increasing reports of failures in structures like buildings, pavements, and dams highlight the need for a more comprehensive approach that considers both design and long-term performance factors.

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Geotechnical Factors:

The stability of buildings, particularly pavements, dams, and retaining walls, is greatly influenced by the geology and soil conditions. To avoid failures, thorough site assessments and suitable geotechnical design are essential.

Human Factors:

Failures may be caused by human error, which includes poor supervision, building errors, and design problems. Throughout the project lifetime, addressing these concerns calls for appropriate training, quality control procedures, and transparent communication.

The study aims to evaluate how petrography, mineralogy, and rock chemistry influence the physical and engineering properties of crystalline rocks in southeastern Nigeria, and to assess their suitability for construction use. It emphasizes that ensuring infrastructure safety requires not only proper design but also high-quality materials, appropriate construction methods, environmental considerations, and ongoing maintenance to achieve long-term reliability



Figure 2: Local basalt quarrying at Ikom (Source; Field work pictures)

1.2 Literature Review

The primary objectives of engineering geology research aim to ensure safety and cost-effectiveness by evaluating geological factors that influence the performance of structures. This involves selecting suitable sites and materials while avoiding unnecessary overdesign. When local materials are inadequate, transporting better materials increases costs, so engineers often improve efficiency by using local alternatives or blending them with higher-quality materials.

Construction projects require a wide range of materials. These, commonly referred to as engineering or building materials, are used in the development of structures such as buildings, bridges, and roads. Examples include bricks, timber, cement, steel, and plastics. These materials can be examined and classified into different categories for use in civil engineering applications.

- Conventional materials
- Different construction materials
- Composite materials
- Intelligent materials

An engineer must be familiar with the characteristics of engineering materials. Only when the qualities of the materials are well known can the right choice of materials be made for a building project. The following categories include some of the most significant characteristics of construction materials

Table 1: Summary of Properties of materials

Group	Properties
Physical	Shape, Size, Density, Specific Gravity etc.,
Mechanical	Strength, Elasticity, Plasticity, Hardness, Toughness, Ductility, Brittleness, Creep, Stiffness, Fatigue, Impact Strength etc.,
Thermal	Thermal conductivity, Thermal resistivity, Thermal capacity etc.,
Chemical	Corrosion resistance, Chemical composition, Acidity, Alkalinity etc.,
Optical	Colour, Light reflection, Light transmission etc.,
Acoustical	Sound absorption, Transmission and Reflection.
Physiochemical	Hygroscopicity, Shrinkage and Swell due to moisture changes

1.2.1 Rocks as Construction Materials

One of the geo-materials used in construction is rock, which may be utilised as building stone, aggregate, concrete, or armour stone. Depending on the necessity for building, naturally existing rocks are mined and crushed to create aggregates with varying sizes and uses.

According to **Johnson and Degraff (1988)**, the size of the crushed and quarry rock materials used in building varies based on the intended usage. They might be coarse or fine. While coarse aggregate passes a 100mm square aperture sieve and is held at sieve No. 4, fine aggregate passes sieve No. 4 (4.75mm) (ASTM, 1978). Aggregate may be used to create a mixture required for building, according to **Blyth and de Freitas (1984)**. The mixes are dependent on the size of the fragments; comparable sizes are used when an open porous aggregate is needed, and a variety of sizes are employed when smaller particles are needed to fill the spaces between the pieces. Many metamorphic rocks like schist are unsuitable for construction due to their flaky, weak structure. Key factors in material selection include cost, environmental impact, and the Factor of Safety (FOS), which ensures stability by relating a material's strength to applied stress. Beneficiation can improve material quality and reduce costs.

The study location is within Oban Massif, located in Southeast Nigeria and covers an area of around 10,000 km² (**Ekwueme et al., 1995**). It is made up of mappable rocks including gneisses, phyllites, schists, and amphibolites that have been invaded by granitic rocks like granites, granodiorites, and dolerites. Like other Nigerian basement rocks, these rocks have undergone many orogenic episodes, including the Liberian (2700 ± 200ma), Eburnean (2000 ± 200ma), Kibarian (1100 ± 200ma), and Pan-African (600 ± 150ma) (Oyawoye 1972). The preferred mineral orientation and the presence and orientation of various features, including as faults, fractures, joints, and xenoliths, all have an impact on the strength of the rocks in the research region.

According to **Egesi and Tse (2012)**, the characteristics of rock materials have a major role in how the rocks react to various pressures depending on how they are used in building projects. Rock mineral compositions, moduli of elasticity, stress-strain relationships, compressive strains at peak stress, and their compressive and splitting tensile strengths are among the mechanical property-related topics covered in this study. Because rocks are aggregates of minerals, their petrography is essential to their assessment as building materials.

Additionally, The suitability of aggregates for concrete is mainly controlled by the parent rock's mineral composition, elastic modulus, and stress-strain behavior, while compressive strength plays a secondary role. Concretes made from dolomite and basalt show better mechanical performance compared to granite. Additionally, petrological characteristics provide insight into mineral composition, which significantly influences the strength and durability of the rocks.

The use of rocks in construction depends on mechanical, physical, petrographic, and geochemical properties. Thorough investigation of these characteristics is essential to ensure the safety and performance of engineering structures. Although detailed testing can be costly and time-consuming, simpler, less expensive methods are available that still provide reliable results for practical engineering applications. More so, the ability to evaluate the short and long-term rock behaviors based on the interactions between various parameters of rock chemistry, petro-physical and mechanical properties is crucial to many geo-engineering facilities. Rocks' mechanical qualities are mostly determined by their petrographic or textural features (**Oyediran and Foghi, 2018**). In addition to serving as a suitable frame of reference in the event that quality rock cores are not easily accessible for the appropriate and trustworthy, mechanical testing required to characterise rockmass, the impacts of these connections and their extent must be well understood. **Zhang (2006)** noted that rock behavior under in-situ stresses is an essential element that must be considered when undertaking earth engineering studies. Rock behavior is governed by both mechanical and petro-physical properties. Mechanical properties—such as Uniaxial Compressive Strength (UCS), tensile strength, shear strength, Young's modulus, and Poisson's ratio—describe a rock's resistance to deformation and failure. Petro-physical properties, including density, P-wave velocity, water absorption capacity, magnetic susceptibility, and electrical resistivity, influence how rocks respond to stress and environmental conditions, affecting their overall performance in engineering applications.

Rock composition and mechanical properties are essential for evaluating engineering behavior such as strength, deformation, and failure mechanisms. Key properties include Uniaxial Compressive Strength (UCS), tensile strength, and shear strength, which define a rock's resistance to different stresses. Additional parameters like Young's modulus (stiffness) and Poisson's ratio (deformation response) help describe how rocks behave under applied loads.

Understanding the relationship between rock properties and strength is essential for engineering applications. Rock strength is influenced by factors such as mineral composition, grain size, porosity, weathering, and anisotropy. Generally, stronger rocks are denser, have lower porosity and water absorption, and exhibit higher P-wave velocities, though these relationships can vary depending on internal structure and mineral bonding

1.2.2 Relevance of Study to contemporary engineering trends

It is significant before going further to presents a comparative evaluation of selected authors on geo-mechanical properties of crystalline rocks used in civil engineering construction. It highlights similarities with the present study and identifies areas of uniqueness.

Blyth and de Freitas (1984) focused on engineering geology classification with emphasis on physical parameters such as density and porosity. The authors established fundamental relationships between density and porosity as indicators of rock strength and durability. Compared to the present research, their work provides the theoretical foundation upon which modern geo-mechanical assessments are built. However, the present study expands beyond these basic relationships by incorporating additional engineering indices such as UCS, ACV, AIV, and LAAV, alongside statistical analysis to provide a more comprehensive evaluation of rock suitability.

Bell (1993; 2007) emphasized the engineering performance of aggregates using parameters such as Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), and Los Angeles Abrasion Value (LAAV). These indices were used to evaluate the durability and suitability of rocks in pavement and concrete construction. While similar to the present study in terms of engineering testing methods, the current research extends Bell's work by integrating petrographic and geochemical analyses with these indices, as well as comparing results across multiple geological regions.

Oyediran and Foghi (2018) focused on the relationship between petrography and the strength properties of crystalline rocks, emphasizing how mineral composition and texture influence mechanical behavior. Their findings align closely with the present study, which also highlights the role of petrography in controlling rock strength. However, the current research is more comprehensive as it combines petrography with field measurements, laboratory testing, and statistical correlations to predict engineering performance.

Ndukauba and Akaha (2012) evaluated the engineering properties of aggregates in the Bamenda Massif, Southeastern Nigeria, using parameters such as specific gravity, water absorption capacity, ACV, and AIV. Their work demonstrated that local basement rocks are generally suitable for construction. The present study is similar in its regional focus and use of standard engineering tests but is unique in its broader comparative analysis with global datasets and its integration of advanced statistical methods to enhance prediction and reliability.

Nyong (2024) and the present study focus on evaluating crystalline rocks in Southeastern Nigeria for engineering construction, emphasizing the role of petrography, mineral composition, and mechanical properties (such as strength, density, and water absorption) in determining rock suitability. However, the attached study advances Nyong's work by adopting a more comprehensive and quantitative approach, integrating petrographic, geochemical, geo-mechanical, and engineering analyses with statistical modeling to establish clear relationships between rock chemistry, mineralogy, and strength. It also expands the scope through a larger dataset, wider spatial coverage, and the inclusion of previously under-evaluated rocks such as columnar basalt, while comparing results with international engineering standards.

Overall, whereas Nyong (2024) provides a foundational petrographic and structural understanding, this study delivers a more holistic, application-oriented, and predictive framework for selecting suitable construction materials.

1.2.3 Determining Strength of Rock Aggregates.

In other to understand the physical properties of crystalline rocks, distinction has to be made between intact rock and rock mass. Intact rock is used to describe a rock sample with no discontinuities like joints, bedding planes and other planes of weaknesses. It is synonymous with rock samples. Rock mass is a mass if rock interrupted by discontinuities with each constituent discrete block having intact rock properties (**Johnson and Degraff 1988**). The use of rocks in construction depends on mechanical strength, physical properties (such as density, porosity, and specific gravity), and petrographic characteristics. However, these factors alone are insufficient, as they do not account for long-term durability, environmental effects, economic considerations, or structural requirements. Understanding the relationships between these properties helps estimate other mechanical attributes, reducing investigation costs while improving safety and material selection in engineering projects. Rocks exhibit wide variations in structure and composition, so simple physical properties—such as specific gravity, density, water absorption capacity, and porosity—are used as index properties for quantitative description. Although easy to measure, these properties provide valuable insight into the mechanical behavior of rocks and help determine their suitability for engineering construction.

1.2.3.1 Chemical Weathering Indicators (CWIs)

Geochemical instruments called chemical weathering indices (CWIs) are used to evaluate the extent of chemical change in crystalline rocks. They are especially helpful for understanding weathering processes in different climates and geological contexts. The Chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), and Plagioclase Index of Alteration (PIA) are examples of common CWIs. The weathering index provides a quantitative measure of the degree of rock weathering and is useful in predicting

rock strength, deformation, and classification. This study examined chemical, petrographically, and engineering weathering indices for rocks such as granite, basalt, and granodiorite, finding that current chemical indices are often unsuitable for engineering applications across different rock types. Understanding the relationship between weathering indices and mechanical properties improves predictions of rock behavior, which is essential for slope stability, mining, and construction design.

1.2.3.2 Effect on Engineering Applications and Rock Strength:

Crystalline rocks are weakened by weathering, which decreases their stability and strength and increases their vulnerability to failure. However, it may be problematic to sample and analyse weathered rocks, which makes it difficult to derive accurate geotechnical characteristics for engineering reasons. For slope stability, foundation design, and other engineering applications, accurate weathering evaluation is essential. In summary, while chemical weathering indices provide useful information, their application to crystalline rocks requires careful consideration of the previously listed parameters. In addition to understanding the local geology, a thorough evaluation of weathering should include chemical, mineralogical, and physical characteristics, and weather conditions.

1.2.3.3 Gravity Specific (SG)

A solid's specific gravity (SG) is determined by dividing its density by the weight of water. According to Punmia et al. (2005), it is a dimensionless unit that expresses the ratio of the densities of rocks and water at a standard temperature of 40°C. Specific gravity has no unit since it is a ratio. It is a crucial indicator for identifying different kinds of rocks and geological formations. It measures the strength of the rock indirectly. Because of their interconnecting mineral grains, crystalline rocks usually have little porosity, which adds to their comparatively high density.

Crystalline rocks usually have a specific gravity of two to three. For instance, the specific gravity of quartz, a typical mineral that forms crystalline rocks, is 2.65. This range also includes a large number of other common minerals that form rocks.

Specific gravity is directly related to rock density and strength, with higher values indicating stronger and higher-quality aggregates (Amah et al., 2012). Because of its strong correlation with density and mechanical strength, specific gravity serves as a useful parameter for estimating rock strength properties, such as Uniaxial Compressive Strength (UCS), particularly in preliminary investigations (Nyong, 2024). It also aids in the classification of construction materials, with typical pavement aggregates having specific gravity values between 2.50 and 3.0 (Matthew, 2010).

1.2.3.4 Water Absorption Capacity (WAC)

Water Absorption Capacity is the amount of water that an aggregate can absorb. It is one of the indirect indices that have been used over time to determine the quality of aggregates used as construction materials. WAC is an engineering index property used to assess a rock's durability and strength, particularly as a construction material or aggregate. It is an indirect measure of the rock's permeability and porosity; generally, stronger, less porous rocks (like many crystalline types) have lower WAC values.

Water Absorption Capacity (WAC) measures how much water aggregates can absorb, with values below 1.0% considered suitable for high-quality construction materials. Higher WAC indicates more voids and lower rock quality. Crystalline rocks, such as granite, generally have low WAC due to their dense structure, though some types like porphyritic granite may absorb slightly more water because of their mineral composition (mica content).

1.2.4 Mechanical Properties of Crystalline Rocks

Crystalline rocks, characterized by interlocking mineral grains, are important in engineering due to their strength, elasticity, and durability, which depend on factors like composition and grain size. Rock mechanics studies these properties and their application in construction. Unlike other materials, rock design is complex because it depends more on in-situ stress conditions and multiple potential failure modes, requiring careful evaluation rather than simple load-based design.

Ugbe, (2019) noted that mechanical properties of rock are significantly influenced by the texture and mineralogical composition of rocks. Sajid and Arif (2014) noted that differences in texture and mineralogical compositions accounted for variations in mechanical properties of rocks. Several tests have been developed to quantitatively describe the mechanical attribute of basement rocks in terms of strength, deformability and velocity of elastic waves.

Strength properties of rocks mainly include uniaxial compressive, shear, and tensile strength, while deformability is described by Poisson’s ratio and elastic modulus. The next section discusses the development and application of these mechanical properties in crystalline rocks.

1.2.4.1 Uniaxial Compressive Strength (UCS)

Rock strength is characterized by compressive, tensile, and shear strength, with Uniaxial Compressive Strength (UCS) being the most used parameter. UCS is determined by applying increasing compressive force to cylindrical rock samples until failure occurs, making it a fundamental test for evaluating rock behavior in geotechnical engineering.

Uniaxial Compressive Strength (UCS) is measured in megapascals (MPa), equivalent to MN/m². Although average UCS values offer limited direct use, they provide useful guidance for site investigations. UCS testing is widely used but can vary due to testing conditions. Standard procedures recommend cylindrical samples with specific dimensions, though both regular and irregular samples can be used if properly prepared. The compressive strength is determined by dividing the failure load by the sample’s cross-sectional area. **Blyth and de Freitas (1984)** presents the ranges of UCS for representative crystalline rock as summarized in Table 2.2. Uniaxial Compressive Strength (UCS) testing is used to evaluate the strength of intact crystalline rocks for classification purposes by applying continuous load until failure. UCS values vary with rock type, weathering degree, and orientation, with unweathered rocks showing higher strength and metamorphic rocks exhibiting greater anisotropy. The test is typically conducted using a compression testing machine, though indirect methods like the Schmidt hammer and point load test can also estimate UCS.

However, these data can be determined indirectly both in-situ (in the field work) and in the absence of a triaxial machine.

(A) Point Load Test:

This test involves applying a concentrated load to a rock sample until failure, and the point load strength index can be correlated to UCS.

(B) Nail Penetration Test (NPT):

This method involves measuring the penetration depth of a nail into the rock, which can be correlated to UCS.

Table 2: Ranges of UCS for different rock types in MN/m²(Blyth and de Freitas, 1984)

Materials	Lowest	Likely	Highest
Granite	100	230	350
Gabbro	150	280	350
Dolerite	150	310	550
Basalt	130	300	500
Gneiss	100	230	350
Quartzite	150	200	310
Sandstone	75	150	350
Limestone	75	145	250
Hornfels	120	300	400

Blyth and de Freitas, (1984)

Basalt generally shows higher strength than granite due to its finer crystal size, although its strength can vary widely when vesicles (gas-filled spaces) are present, which weaken the rock. In foliated rocks like schist and gneiss, strength is influenced by foliation and mineral arrangement. Gneiss tends to be stronger than schist because of better crystal interlocking, but variations occur due to differences in mineral composition and the orientation of foliation relative to applied stress. Uniaxial Compressive Strength (UCS) is a key parameter used to evaluate rock strength for engineering applications such as slope stability, tunnelling, and infrastructure construction. Although UCS testing can be expensive and complex, it is essential for design purposes. Standard testing requires

cylindrical core samples, though alternative methods exist. To reduce costs, especially during early site investigations, indirect methods like the Schmidt Hammer are commonly used to estimate UCS efficiently.

(C) Schmidt Hammer Rebound (Comeback) Test:

Ernst Schmidt, a Swedish engineer, created the Schmidt Hammer in 1948 for non-destructive concrete hardness testing. Since then, it has been used to assess the strength of rock materials (ISRM 1978a). It is a portable, user-friendly device that may be used for both in-situ strength testing in the field and laboratory testing of rock material. After the hammer is released by its spring against the rock surface, the test's value is noted. It is based on the idea that the observed rebound of a steel hammer mass on a rock surface when it is pushed with 0.075 kg/m of energy will be proportional to the hardness of the materials, which may be associated with strength (Deere and Miller, 1966; Johnson and Degraff, 1988). ISRM (1981), BS812 part 110 (1990), and ASTM D5731 (2001) have all described how to conduct tests to get correct results. Before testing, the hammer must be calibrated using the calibration anvil that the makers provide.

The test surface has to be smooth or uniform, and the test direction should be downward vertical at a right angle to the rock or block face. An unbroken rock sample may be tested in-situ in the field or in a lab by properly securing it against movement and vibration by placing it on a concrete floor (Oyediran and Foghi, 2018). Each sample should undergo a total of 12 to 20 tests, with rebound results sorted in decreasing order. The average of the top 50% is computed, while the bottom 50% value is discarded. The rebound hardness is calculated by multiplying the average value by the adjustment factor. The Schmidt Hammer was proven to be very dependable by Katz et al. (1999) for estimating the UCS of basement rocks. According to Amuda et al. (2014), compressive strength and the N value of rebound hammer and specific gravity are directly correlated, and UCS may be calculated using the Schmidt Hammer.

Using Schmidt Hammer to determine the UCS of rock, particularly at the preliminary site investigation stage, can help lower the cost of engineering construction on and with rock and increase structural safety since it is an accessible and simple piece of equipment.

1.2.5 Crystalline Rocks' Engineering Properties

Crystalline rocks are important geomaterials widely used in civil engineering, including as aggregates in pavements, construction stones, armor stones, and concrete. Their suitability for specific applications depends on their physical properties. The engineering features of rocks refer to the characteristics they exhibit when used in construction, which determine their performance and reliability in engineering works.

These characteristics are connected to the rocks' physical characteristics (Williamson 2005). Rocks' engineering qualities include:

- The resistance to abrasion,
- Resistance to impact,
- resilience and resistance to crushing.

Engineering features of rocks are evaluated using specific test parameters to ensure construction safety and stability. One key property is the **Los Angeles Abrasion Value (LAAV)**, which measures the resistance of rock aggregates to wear and abrasion.

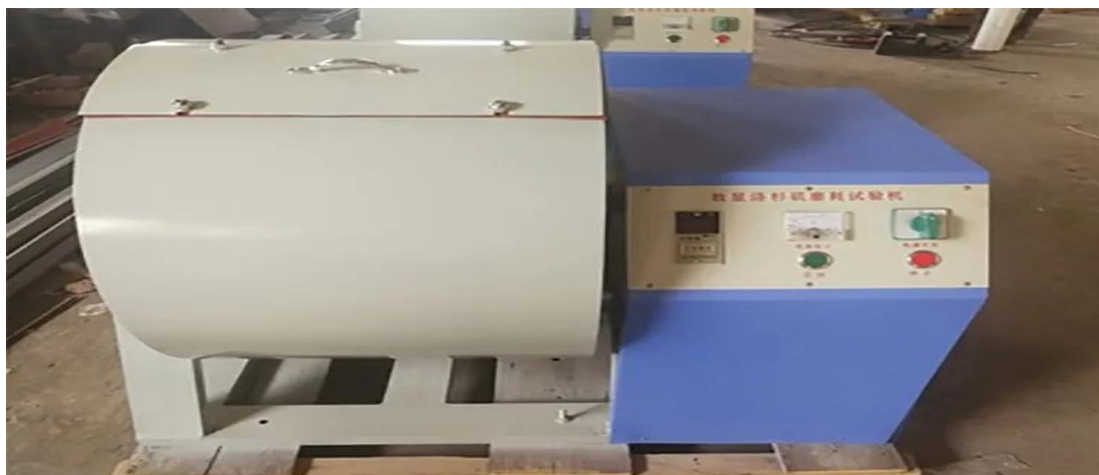


Figure 3: Los Angeles Abrasion testing machine (source: Civil Engineering laboratory, University of Cross Rivers State)

The Los Angeles Abrasion test, as described by ASTM (1978), uses equipment such as a steel drum, steel balls, sieves, and a weighing balance to determine the abrasion resistance of rock aggregates. Typical values vary by rock type, with basalt showing favorable results (10–17%). Standards indicate that LAAV values below 30% are suitable for most construction works, while values above 50% are unsuitable. Guidelines from BSI and Shetty further specify limits for pavement and concrete applications. Additionally, Nyong (2024) observed that LAAV is inversely related to Uniaxial Compressive Strength (UCS), meaning rocks with higher abrasion values tend to have lower strength.

Aggregate Crushing Value (ACV) is another important property used to assess rock performance. It is a measurement of an aggregate's ability to withstand crushing under compressive pressures. For concrete used for roads and pavements, the crushing value of aggregate is limited to 30%, but 45% may be allowed for other constructions, according to Shetty (2005). For concrete used for roads and pavements, the crushing value of aggregate is limited to 30%, but 45% may be allowed for other constructions, according to Shetty (2005). The resistance of aggregates to impact loads is indicated by the aggregate impact value (AIV) (Williamson, 2005). According to Matthew (2010), aggregates used for wearing courses should have an impact value of no more than 30%, however the maximum allowable value for bituminous macadam is 35%. BSI (1990) provides a process to perform out AIV. According to Jayawardena (2008), there is a linear positive association between AIV and LAAV, with LAAV occurring between 1.64 and 1.38 times AIV. He clarified that after AIV has been established, the approximate value of LAAV may be calculated since LAAV involves more samples than AIV.

1.3 Location and Geology of the Study Area.

A portion of the southeast Oban Massif is included in the research area. It includes the Cross River State local government areas of Akamkpa, Yakurr, and Ikom. Geographically, it is located between latitudes 0501012311N and 0505813811N of the equator and longitudes 00800510511E and 00804510511E of the Greenwich Meridian. Its estimated total area is 10,000 km². Rock outcrops, rock exposures along water channels, and both active and abandoned quarries were among the locations visited. The research region continues into the dense tropical rainforest and is delineated by a strong sedimentary basement contact at Awi.

The main Calabar-Ikom highway provides access to the region. Numerous minor roads that were built because of quarrying operations and other local agricultural and socioeconomic activities further improved accessibility. Other parts of the research region were difficult to reach due to their undulating landscape and deep forests. Traverses must be cut in order to reach the regions of interest in these circumstances. To reach several outcrops situated amid the challenging and thick terrain, local pathfinders were hired.

The research area's geologic location indicates that it is part of Nigeria's Precambrian Basement Complex. During the Precambrian, the Nigerian Basement Complex saw many periods of deformation. It is believed that deformation and metamorphism occurred simultaneously. (Oyawoye, 1972).

Crystalline igneous and metamorphic rocks with a variety of categorised mineral assemblages make up Nigeria's basement complex. They may be roughly classified as either older granites plus minor rocks, the Pan-African intrusive series, the schist, or the ancient gneiss-migmatite complex (Adeyemi & Oyediran, 2005). Crystalline igneous and metamorphic rocks with a variety of categorised mineral assemblages make up Nigeria's Basement Complex. They may be generically classified as older granites plus minor rocks, the Pan-African intrusive series, the Schist, and the ancient gneiss-magmatite complex (Adeyemi & Oyediran, 2005). According to Dada et al. (1998) and Elueze (2000), the Schist belts are mostly found in Nigeria's western half, while some have been identified in the country's center and southern regions.

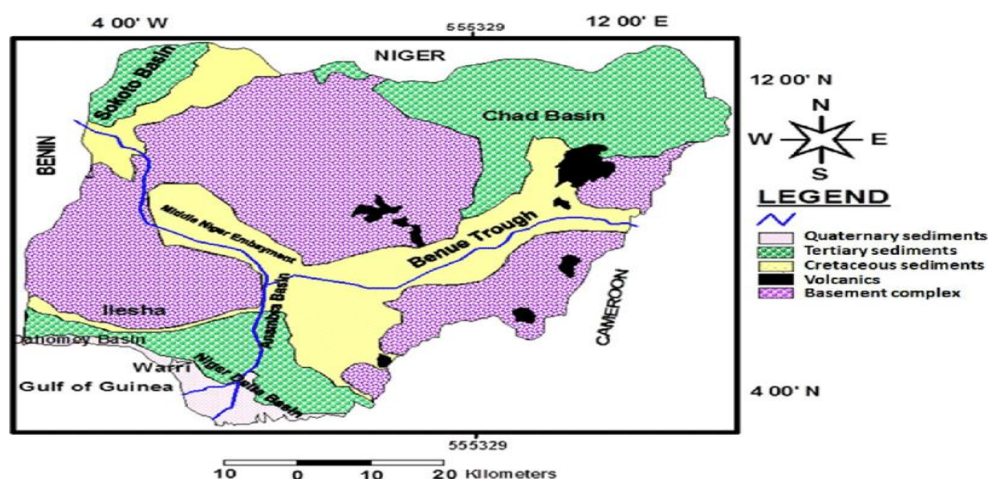


Figure 4: Map of Nigeria showing the location of Basement rocks (Nwajide, 2013)

The geology of the Ikom Embayment, the research region, and the Oban Massif will be taken into account in the local geology. Three primary rock units make up the Oban Massif, according to research done by **Rahman et al. (1981)** and **Ekwueme and Onyeakocha (1985)**. These are:

- Phyllites, quartzite, amphibolites, pegmatites, gneisses, and migmatite rocks
- Granodiorite and granites are among the older intrusive granites.
- Dolerites without metamorphosis

Granites, pegmatites, granodiorites, and diorites have intruded into these rocks in some locations. The Oban Massif has a variety of gneisses. These consist of migmatite, biotite, and kyanite gneiss (**Ekwueme, 1989**); the Oban Massif also contains quartzite. Their strong resistance to weathering is what makes them stand out.

Columnar basalt makes up the majority of the Ikom region. These columnar basalts are believed to have originated from basaltic flow, cooled, and quickly solidified, giving them a fine-grained appearance. Olivine, pyroxene, and a little amount of hornblende are the predominant minerals. The dark hue of the basaltic rocks is caused by the presence of calcic plagioclase with a very low quartz concentration.

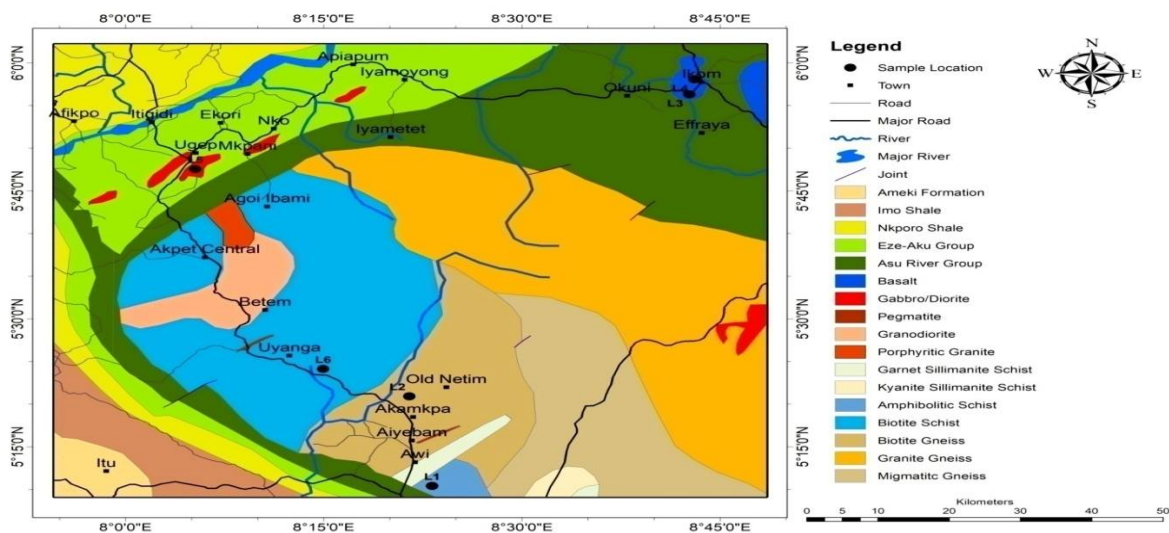


Figure 5: Geologic map of the study area (Source: ArcGIS generated)

As previously mentioned, the geology of the Oban Massif and its surroundings is like that of Nigeria's other Basement Complexes. The rocks of the Oban Massif were similarly impacted by the same orogenic events that affected other complexes, with Pan-African being the most prevalent, while other orogenic imprints were also seen. This manifests itself as structural orientation. Most structures have significant N-S and NE-SW

orientations with minor NW-SE orientations, including the linear structure, joints, faults, veins, and other structures like foliations. To provide crushed aggregates for building, these rocks are being quarried. Additionally, there are artisanal miners who extract valuable minerals like amethyst and lepidolite. Their operations are unregulated, and if they are not quickly observed, they might pose a threat to the environment. The research area's geology map is shown in Figure 3.

The research area's two main wind systems oversee the local climate. These are the harmattan and the south-west wind, which bring the rain, and the north-east trade wind, which brings the dry season. Streams overrun their boundaries during the rainy season, which peaks in July and early August. However, NIMET reports that the average annual rainfall is around 3000 mm (**Agabi, 2016**).

The temperature never rises to over 35 degrees Celsius and often falls between 24 and 28 degrees. The vegetation in the study region is significantly impacted by changes in the local climate. Tall trees, bushes, and undergrowths are among the many plant species that have emerged because of the high rates of precipitation and the prolonged rainy season. The tropical rainforest is one of the nation's richest ecosystems because of its natural variety. Numerous tree species have canopies that decrease in insolation. These provide the study area's wild animal's shade. Additionally, there is grass and bushes, some of which reach heights of two to five meters. In the jungle, some trees may reach heights of 30 to 50 meters, while emergent trees can reach much higher heights. In the research region, secondary vegetation was also noted. The residents' socioeconomic activities are to blame for this. A typical vegetation of the research region is shown in Figure 4.



Figure 6: Typical vegetation of the study area (Sources; field work pictures)

1.3.1 Research Methodology

The structural research- roadmap of this study is given in the figure below:

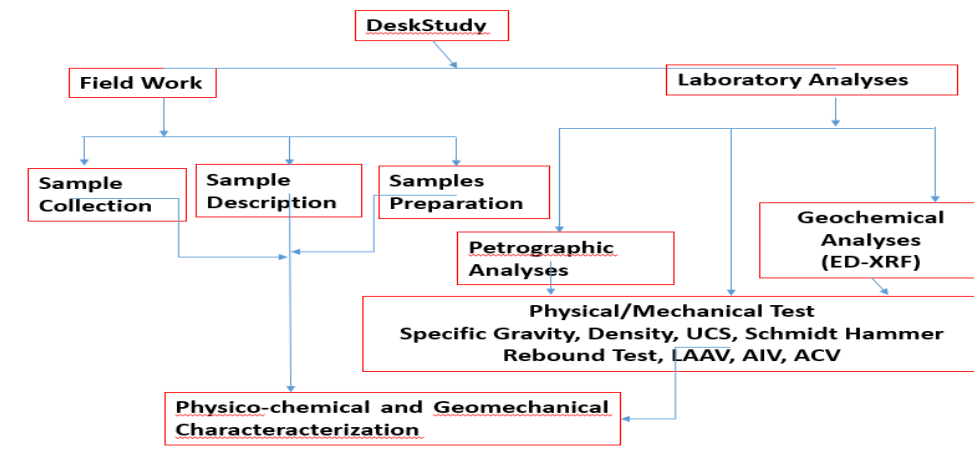


Figure 7: Roadmap to study diagram.

Desk Study and Fieldwork

The study was conducted in three stages, beginning with desk work. This initial phase involved gathering and reviewing existing information from both published and unpublished sources, including literature, maps, and insights from stakeholders such as quarry operators, construction workers, and consultants. This helped build background knowledge and context for the research area. Additional understanding was gained by reviewing studies on rock use in other regions. Due to the absence of an engineering geological map for southeast Nigeria, the study relied on available topographic and geological maps of Cross River State and the broader region.

Fieldwork was the second stage of the study and was carried out in two phases: a reconnaissance survey and detailed field mapping. The reconnaissance phase followed the desk study and involved visits to the study area to collect preliminary information on quarry locations, rock types, outcrops, their properties, and local socioeconomic activities. The fieldwork took place in the Oban Massif and surrounding areas in southeast Nigeria, including locations in Akamkpa, Yakurr, and Ikom local government areas of Cross River State. Observations made during fieldwork also included collecting representative rock samples for subsequent laboratory analysis.



Figure 8: Sampling physical evidence Amphibolites at Old Netim. (Source: Field work)

Field mapping was conducted using a 1:100,000 topographic map with a vellum overlay for accurate plotting. Observations covered active and abandoned quarries, natural outcrops, and stream channels to assess rock characteristics and weathering. GPS, hand tools, notebooks, and a digital camera were used for location tracking, sample collection, and documentation.



Figure 9: Abandoned crush rock quarry at Okomita. (Source: Field work)



Figure 10: Local basalt quarry at Ikom (Source: Field work)

Other field equipment used during the field exercise included dilute hydrochloric acid (HCL) which was used to identify carbonate rocks or minerals. Hand lenses were used to observe texture of rock samples in the field. Compass-clinometer was used to obtain attitude of structural features while metre rule and tape was used to take linear measurement, and the L-type Schmidt Hammer was used for the measurement of in-situ rock strength.

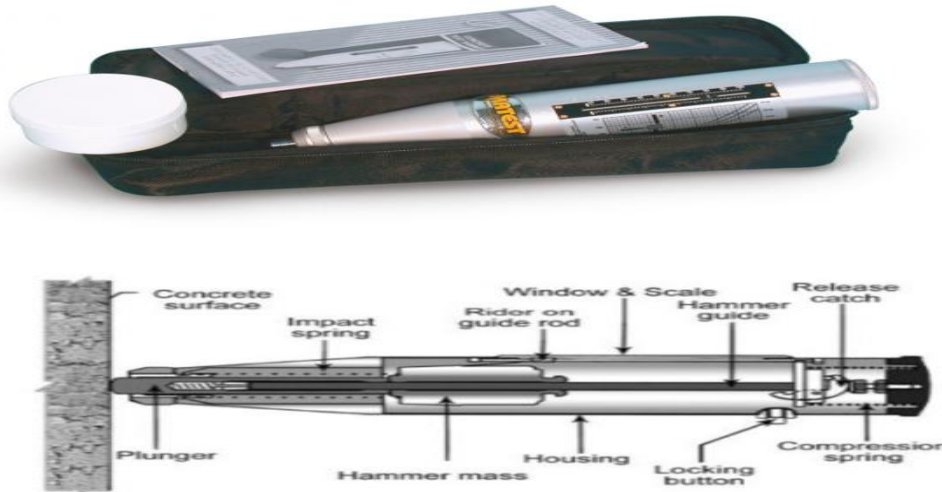


Figure 11: Schmidt Hammer was used for the measurement of in-situ rock strength (Source: civil engineering department – Cross Rivers state University of Science and Technology)

The field study involved a month-long geological mapping exercise, following established methods to collect and map data on rock characteristics and distribution. It was conducted during the dry season to improve access to outcrops along river channels, with the help of local guides who supported navigation and fieldwork activities. A typical rock outcrop in the research region is seen in figure 10.



Figure 12: Measurement of in-situ rock strength using L type Schmidt Hammer (Source: Field work)

1.4 Sample Collection

Thirty-six rock samples representing five rock types were collected from eight locations in southeastern Nigeria to assess their geo-mechanical and physio-chemical properties for civil engineering use. Samples were obtained from quarry floors, exposed rock faces, and outcrops, using tools like a sledgehammer and geological hammer after proper inspection and documentation.

Key features such as discontinuities, structural elements, texture, and field relationships were recorded to characterize the rocks. The samples were carefully labeled and stored in ventilated calico bags to prevent chemical alteration, then transported to the laboratory for further analysis. GPS coordinates of each site and in-situ strength test results were also documented in field notes.



Figure 13: Sample collection and labeling (Source: Field work)

1.5 Sample Preparation

Every rock sample that was gathered from the research area was put through the appropriate sample preparation procedures in compliance with the guidelines for every test set. geochemical laboratory. In compliance with BSI (1975b), samples for Uniaxial Compressive Strength (UCS) were cut and formed into cubes measuring 10x10x10 cm.

Jaw crushers of the Retsch JXLE1 D09 type were used to smash samples for engineering and physical testing into aggregates. According to BS 812, BSI (1975b), and GRFN (1997), the aggregates' pertinent sizes for engineering tests were followed. After being properly prepared, labelled, and kept in a dry, well-ventilated space, all of these samples were transported to the appropriate laboratory for the necessary testing. Extreme caution was used during sample processing to prevent sample contamination, which might affect test findings. To provide quality control, samples were sometimes duplicated as controls. The duplicate sample data were not used for further analysis and assessment.

The field samples were produced and handled in accordance with the applicable authorities in order to perform the geo-mechanical assessment and physico-chemical analyses of crystalline rocks from the research region. They were transported to the lab for further laboratory analysis and pertinent mechanical testing.

1.6 Mechanical and physical testing

Physical and mechanical testing were carried out in the lab for the geo-mechanical assessment of crystalline rocks from the research region. The geo-materials' strength, resistance to impact, abrasion, and crushing are all crucial characteristics for the construction sector. These attributes are connected to the physical features of the rocks, including density, water absorption capacity, and specific gravity. The ASTM (1978, 1980, 1998), BSI (1975, 1978, 1983, 1996), ISRM (1970), and GFRN (1997) standards were followed in conducting these laboratory tests. Clay balls, organic materials, and other undesirable materials were not present in the materials utilised for laboratory studies for mechanical and physical testing. The following sections describe how the mechanical and physical tests were conducted on these typical samples:

1.6.1 Gravity Specific (SG)

One of the physical property tests performed on representative samples from the research region was specific gravity. The strength of the rock may be inferred from this test. It is known that stronger and denser rocks have greater specific gravity values. Three kilograms of aggregates with a diameter of less than ten millimetres were used to measure the specific gravity. A balance with a capacity of three kilograms or more, a wide-mouthed glass vessel, a tray, a dry, soft, absorbent cloth, an airtight container big enough to hold the sample, a wire basket, and a thermostatically controlled oven with a temperature range of 105 to 110 degrees Celsius are among the tools used. The sample is screened on a 10mm BS standard sieve and carefully washed to eliminate tiny dust particles. It is then placed in a wire basket submerged in distilled water and left to stand for 24 hours \pm 30 minutes at a temperature between 22 and 32 degrees Celsius. Following the immersion phase, the sample is surface dried, weighed in air, and then oven dried at 100–110 degrees Celsius.

Specific Gravity is obtained mathematically using:

$$SG = \frac{M_2 - M_1}{[(M_4 - M_1) - (M_3 - M_2)]}$$

Where M₁ = Weight of vessel
M₂ = Weight of vessel + dry sample
M₃ = Weight of vessel + Sample + water
M₄ = Weight of vessel filled with water alone

Specific gravity (SG) has no unit since the parameters include weight units in both the numerator and the denominator. An indirect indicator of a rock's strength is its specific gravity. The strength of the rock increases with increase in the specific gravity value.

1.6.2 Density

The density test is another physical test that was performed on the representative sample. The unit weight of rock is its density. A cylindrical metal and a balance sensitive to 0.5% of the weight to be weighed were used for the density test. Using a scoop, the measure was filled to overflow. The aggregate was released from a height of around five centimetres above the measure's top. After that, a straight edge was used to level the aggregate's surface.

The net weight of the aggregate was then determined using the relationship below;

$$D = \frac{W_3 - W_1}{V}$$

Where W₁ = Weight of measure
W₃ is weight of measure + loose aggregate
V = Capacity of Cylinder

The significance of understanding the density of crystalline rocks is that it provides insight into the suitability of the rocks for various construction works.

1.6.3 Water Absorption Capacity (WAC)

One of the physical tests performed on the representative sample from the research region was water absorption capacity (WAC). Aggregates that passed the BS standard 65mm sieve and were retained on a 63mm sieve were used for this test. An oven, a wire mesh basket with a capacity of at least 1 kilogram, trays, and dry, absorbent clothing are among the equipment used.

Among the methods used are:

- Weighing aggregates to around 1 kilogram and completely cleaning and drying them to remove any clay residue.
- Putting the aggregate in a wire mesh basket and immersing it in water for a whole day.
- The aggregates were weighed after being dry using dry absorbent cloths for a whole day, and the weight was recorded as M₁, which is saturated surface dry.
- After that, the dried samples were kept at a steady 105°C for an hour in a well-ventilated oven.
- After an hour, the samples were taken out and measured; the weight of the oven-dried sample was noted as M₂.

Water Absorption Capacity was then determined using the relationship below;

$$WAC = \frac{M_1 - M_2}{M_1} \times 100$$

Where M₁ is the saturated surface dry.

M₂ is an oven dried sample.

Water Absorption Capacity (WAC) is expressed as a percentage because it represents how much water a rock sample can absorb relative to its dry weight. It gives insight into the porosity and durability of the rock. The higher value in some cases may be due to the higher amount of voids in the samples. This usually indicates that the rock contains more voids, pores, cracks, or microfractures within its structure. A higher WAC percentage reflects greater porosity, which often reduces the overall strength and durability of the rock.

1.6.4 Uniaxial Compressive Strength (UCS)

One of the mechanical tests performed on the typical samples from the research region was the uniaxial compressive strength (UCS). The test's main goal was to determine the rock's strength, which would indicate how workable it would be as a foundation and building material. A cylindrical core sample with a length-to-diameter ratio of 2 to 2.5 (NX cores) may be used for the UCS test. If two opposing flat surfaces are available for loading, it may also be done on irregular samples or cubes. Simpson's Rule is used to compute the surface area. Cubic samples were utilised in this study. The digital compression testing machine (FIG. 3.13) is another piece of equipment utilised to perform the test.

The process used to determine UCS included cutting the rock samples into 10x10x10 cm cubes and grinding the sample's surface parallel to a tolerance of 0.025 mm to provide consistent loading. After that, the specimen was loaded axially to failure in a compressive testing apparatus. The compression machine's dial gauge was then used to determine the pressure at failure.

The relationship was used to determine the sample's uniaxial compressive strength.

$$\sigma = \frac{P}{A}$$

Where σ is the compressive strength (MN/M²)

P = Maximum load (MN)

A = Loading area (M²)

Uniaxial Compressive test is an expensive and destructive rock strength determination method. The sample tested can no longer be used for any other test. The values of UCS provide insight into the workability of rocks. Rocks with higher values of UCS are better construction materials compared to rocks with lower UCS values.



Figure 14: Determination of the Uniaxial compressive strength of rocks from the study area (Source: University of Cross River State Civil engineering laboratory)

1.6.5 Schmidt Hammer Rebound (SHR) Test

Another mechanical test performed on representative samples from the research region is the Schmidt Hammer rebound test. This is an easy-to-perform, non-destructive strength test. This test's ability to be performed both in-situ and in a lab is one of its main benefits. For the current study, the Schmidt Hammer test was conducted both in the field and in the lab, and the outcomes were noted in each instance. The L-type hammer was used, and the testing process followed the manufacturer's instructions.

The test method was gently striking the hammer against a smooth, hard surface to release the plunger from a locked state. The Hammer was now prepared for action. Making sure the rock or rock material to be examined had a smooth surface was the next step. If the equipment has a rough surface, the manufacturer offers a smoothed stone. The hammer was used firmly to the surface of the materials to be evaluated after the surface had been smoothed. This procedure will generate an impact by releasing the spring-loaded weight from its locked position. The sliding index is read to the closest whole integer while the hammer is still in the testing position, and the value is noted. Prior to the test, the hammer was pre-calibrated.

In each example, ten to eighteen tests were conducted, and the results were documented in order of magnitude. The sample's Schmidt Hammer Rebound value was determined by averaging the last 50% of data and excluding the lowest 50%.

The test provides an indicator of the compressive strength of rock materials and is inexpensive and non-destructive. Rebound number (N) often matches the UCS values.

1.6.6 The value of Aggregate Crushing Value (ACV)

One of the engineering tests performed on representative samples of the research region is the Aggregate Crushing Value (ACV) test. This test gauges how well aggregates, which are used in construction, withstand crushing stresses placed on buildings. This test is intended to assess building aggregates' ability to crush under extreme strains. Three kilograms of crushed aggregates that passed the BS standard sieve size of 14 mm and were retained on a sieve size of 10 mm were used for the ACV test. A steel cylinder with open ends and an internal diameter of 152 mm, a square base plate, and a plunger suspended from a 150 mm piston with a hole cut across the plunger's stem in the cylinder were among the materials used. A tamping rod with one rounded end, measuring 16 mm in diameter and 450 mm in length, a cylindrical measure with an internal diameter of 115 mm and height of 180 mm, a 3 kg capacity balance, and a compression testing apparatus.

The test process entails adding the test samples to the cylindrical mould in three about equal-height layers, each of which is tamped with a tamping rod 25 times. After the aggregate's surface was levelled in the mould and the levelled sample was placed in a compression testing apparatus, the aggregate's weight was measured and labelled as "A." To reach 40 tonnes (400KN), the machine was loaded at a consistent pace of 4 tonnes (40KN) for around ten (10) minutes.

The substance was dumped into a dry pan once the mould was freed after the allotted ten minutes had passed. The proportion that passed through a 2.36 mm BS standard sieve after the crushed material was mechanically sieved was noted as "B."

Aggregate Crushing Value (ACV) is expressed as a percentage because it represents the proportion of crushed (fine) material produced when an aggregate sample is subjected to a standard compressive load. ACV measures how much of the aggregate breaks down under pressure.

It is calculated as:

$$\text{ACV (\%)} = \frac{\text{Original of weight of crushed fines}}{\text{Sample weight}} \times 100$$

$$\text{ACV} = \frac{B \times 100}{A}$$

Where ACV = Aggregate Crushing Value
B = Weight Passing Sieve Size 2.36mm
A = Total Weight of Sample

The aggregate is better for civil engineering projects when the ACV value is lower. When opposed to weathered samples, fresh samples often have greater ACV values.

1.6.7 Impact Value Aggregate (AIV)

Another significant engineering test that was performed on representative samples from the research region was the aggregate impact value (AIV) test. This gauges how durable the aggregates used in civil engineering building projects are. The purpose of this test is to assess how well aggregates withstand impact and dynamic stresses. It provides a measure of the aggregates' ability to withstand crushing under impact.

Five kilograms of aggregates that passed the BS standard sieve size of 12.5 mm and were kept on a sieve size of 10 mm were used for the AIV test. A cylindrical steel cup with an interior diameter of 10.2 mm and a length of 5 mm that was fastened to the metal base of the impact testing equipment, a hammer weighing 14 kg, and a balance with a capacity of 5 kg or more were the tools used to determine the Aggregate Impact Value (AIV). The steel cup was filled in three equal levels as part of the test procedures, and each layer was tamped around all sides for twenty-five blows. The specimen is exposed to 15 blows while the metal hammer is set up to fall freely from a vertical height of 380 mm onto the test material. The AIV test conducted on representative samples from the research region is shown in FIG. 3.15. The crushed specimen was then sieved through a BS standard sieve size of 2.36mm. The material passing the sieve was weighed and recorded as "w1," while the total weight of samples was classified as "w2."

The relationship below was used to calculate the Aggregate Impact Value (AIV);

$$\text{AIV} = \frac{W_1 \times 100}{W_2}$$

Where AIV = Aggregate Impact Value

W_1 = Weight of sample passing 2.36 sieve

W_2 = Total weight of sample.

AIV is expressed as a percentage. It is also known as the toughness of aggregates. The lower the value of AIV, the better the aggregate as construction material



Figure 15: AIV test on representative samples (Source: University of Cross Rives Civil engineering lab)

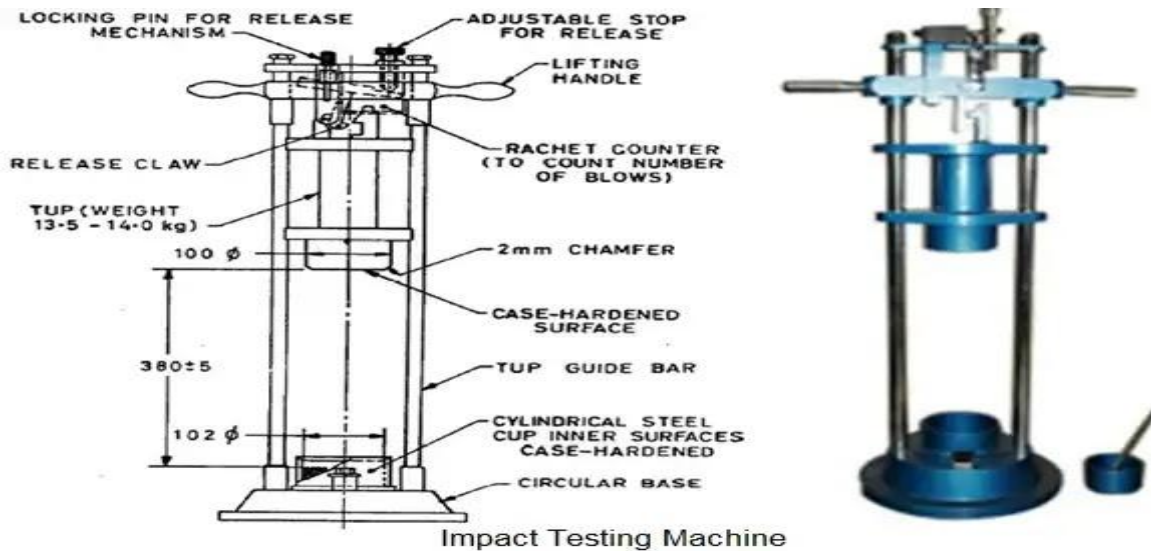


Figure 16: Schematic image of a labeled AIV impact testing machine (Source: University of Cross Rivers Civil engineering lab)

1.68 Los Angeles Abrasion test

Los Angeles Abrasion test used to assess the geo-mechanical properties of crystalline rocks from the research region was to determine how resistant gravel used in pavement construction is to try polishing. This test is done to evaluate the resistance of aggregates to abrasion and impact, which simulates conditions like:

- Traffic load on roads
- Mechanical handling
- Weathering effects

The tests come in many classes, each of which uses a certain quantity of steel balls. The Los Angeles Abrasion test was used for this investigation in compliance with ASTM C131 (1978) grade B. Eleven steel balls with a diameter of around 48 mm were utilised as the abrasive charge in this grade. 2.5 kg of the 5 kg of crushed aggregates were kept at the BS standard sieve size of 12.5 mm, while the remaining 2.5 kg passed the BS standard sieve size of 20 mm. passes through a 12.5 mm sieve and is held on a 10 mm BS sieve. A drying oven, trays, a steel spinning drum (Los Angeles Testing equipment), and a scale with a 5 kg capacity are additional test needs. The sample was oven dried at 105°C as part of the test procedure, and it was then allowed to cool. After cooling, the aggregates were put into a cylindrical drum with the top and abrasive charge securely fastened. After 500 revolutions, the machine was stopped, and the material was released into the tray. The coarse fractions that were retained were weighed after the whole dust was put on a 170mm BS standard sieve. The Los Angeles Abrasion Value (LAAV) is the result of the test. It gauges how resistant rock aggregate is to car polishing. Better building aggregates are produced with lower LAAV values.

Los Angeles Abrasion Values (LAAV) are the test results that are derived from the relationship;

$$\text{LAAV (\%)} = \frac{\text{weight of material lost (fines produced)}}{\text{original sample weight}} \times 100$$

OR,

$$\text{LAAV} = \frac{W_1 - W_2}{W_1}$$

Where LAAV = Los Angeles Abrasion Value

W_1 = Original mass of aggregate

W_2 = Mass of aggregate retained

LAAV is expressed as a percentage. It shows the proportion of material that has worn away or broken down. Using a percentage makes it easy to compare the durability of different aggregates, regardless of sample size



Figure 17: Los Angeles Abrasion test grade B (Source: University of Cross Rivers State Civil engineering lab)

1.7 Statistical Analyses

To properly present, assess, and interpret the collected data, certain statistical analyses were carried out during the geo-mechanical assessment of crystalline rocks from the research region.

Descriptive statistics such as the mean, standard deviation, and ranges were helpful. Additionally, multivariate analysis (correlation, regression analysis) was used for interpretation. When needed, charts and models were plotted using programs like ROCK WORKS 15, SURFER 13, and GRAPHER 10. Each of them contributed to the analysis of the collected data.

II. RESULT AND DISCUSSION

2.1 Laboratory Data Analysis.

The chapter presents results from various tests conducted on crystalline rock samples to evaluate their suitability for construction purposes. These results were analyzed and interpreted to assess their performance in engineering applications. Key physical properties used to describe the rocks include specific gravity, density, porosity, and water absorption capacity, which are essential for understanding rock behavior. The physical and engineering characteristics of rocks are summarized in Table 3.

Twelve (12) typical samples, including two amphibolites, two granites, four basalts, two gabbro, and two granodiorites, were analyzed from Table 3. Density, specific gravity, and water absorption capacity are the index parameters of importance for this investigation. Density values vary from 2.47 g/cm³ for gabbro to 2.70 g/cm³ for basalt. The density of the rocks under study was found to decline in the following order: basalt > granite > amphibolites > granodiorite > basalt, with granite and amphibolites having almost equal densities.

Reynold (1997) had previously shown that a decrease in silica concentration often results in an increase in rock density. When table 3 and table 2 are compared, the research area's results match his previous submission. This discovery implies that the silica concentration of rocks may provide information about their density, which is a crucial index feature. Density is crucial for mix ratio design in concrete production for a variety of building projects, even if it is not a sufficient criterion to describe the strength or quality of rocks on its own. Additionally, according to Blyths and de Freitas (1984), there is a correlation between rock density and porosity; hence, understanding rock density will provide insight into porosity (Table 5).

Table 3: Results of physical and engineering properties of rock aggregates from the study area

S/n	Rock types	Amphibolite	Granite	Basalt	Basalt	Basalt	Gabbro	Granodiorite					
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
1	Density (g/cm ³)	2.58	2.56	2.57	2.59	2.70	2.66	2.61	2.68	2.49	2.47	2.53	2.50
2	Water Absorption Capacity (WAC)	0.51	0.46	0.22	0.25	0.40	0.31	0.86	0.75	0.86	0.76	0.56	0.50
3	Specific Gravity (SG)	2.72	2.71	2.65	2.62	2.98	2.74	2.72	2.70	2.64	2.63	2.57	2.55
4	Aggregate Crushing Value (ACV) %	16.6	18.6	20.67	18.70	15.6	16.5	16.6	19.5	20.7	19.5	17.98	16.60
5	Aggregate Impact Value (AIV) (%)	11.8	14.5	22.30	19.20	11.5	13.3	12.9	11.3	11.7	12.2	10.40	10.20
6	Los Angeles Abrasion Value (LAAB) (%)	24.0	22.7	26.16	21.80	19.52	21.2	21.8	22.6	22.52	23.4	21.30	20.40

Table 4: Relationship between density and porosity of rocks

CLASS	Density (g/cm ³)	Description	Porosity (%)	Description
1	Less than 1.8	Very low	Over 30	Very high
2	1.8-2.2	Low	30 – 15	High
3	2.2 – 2.55	Moderate	15 – 5	Medium
4	2.55 – 2.75	High	5 – 1	Low
5	Over 2.27	Very high	Less than 1	Very low

The connection between density and porosity rocks is summarized in Table 5 following Blyths and de Freitas (1984). It is evident that rocks with greater densities have lower porosity values. As a result, samples from the research region may be categorised as having moderate to high density values. This translates to porosity levels that are medium to low.

Because they can readily withstand water flow, rocks with high density and low porosity values are often used as building materials.

Another index characteristic of rocks is Water Absorption Capacity (WAC), which provides an indirect evaluation of other rock qualities such as permeability, which may be related to mechanical behaviours and rock strength. According to Table 9, the water absorption capacity of rock samples from the research region ranges from 0.22% in granite (average value of 0.24%) to 0.86% in gabbro (average value of 0.81%). The average value of granodiorite is 0.53%. WAC averages 0.58% for basalt and 0.49% for amphibolite. It is evident that the rocks in the studied region have WAC values of gabbro, basalt, granodiorite, amphibolite, and granite in decreasing order. According to Akpokodjie's prior recommendations for acceptable building materials, all of the examined rocks had values below 1% (1992).

Rock permeability may be indirectly measured using water absorption capacity. WAC and permeability have a linear connection; hence low WAC values immediately indicate poor permeability. The rocks from the research region are useful as building materials because of their comparatively low WAC values. These values align with the findings of Mallo et al. (2012), who recommended against using extremely porous and permeable building materials due to the potential buoyancy impact.

Rocks' capacity to absorb water decreases as silica concentration rises and increases as weathering rate increases (Amah et al., 2012). Weathering may be the cause of the relatively high value (0.86%) seen in certain gabbro and basalt.

The examined rocks may be categorised as suitable building materials based on ASTM (1990). This is because all rocks from the examined region fell under the 1% maximum limit of WAC as excellent building materials.

Specific gravity and water absorption capacity are inversely correlated. It is evident that rocks with a greater specific gravity often have a lesser capacity to absorb water.

The ratio of a rock's density to the unit weight of water is indicated by its Specific Gravity (SG), a dimensionless metric. It provides an indirect indicator of the strength and quality of rocks, making it a crucial metric. When utilised for building, rocks having a greater specific gravity provide better results since their compressive strength is likely to be higher. The specific gravity of the rock units under study varies from 2.55 in granodiorite (average of 2.56) to 2.98 in basalt (average of 2.79). Gabbro and granites seem to have comparable SG values (2.64). The mineral composition of basalt, which tends to include more ferro magnesian minerals, which are denser and heavier in weight, but less quartz, is responsible for the comparatively high SG values found. The study area's specific gravity values are entirely in accord with the ranges of values for crystalline rocks described in Bells (2007) and Blyth and Freitas (1984). This is seen in Table 6.

Table 5: Typical values of road stone properties of common aggregates

rock type	Specific gravity	Water absorption capacity (%)	Aggregate crushing value (%)	Aggregate impact value (%)
Basalt	2.91	0.9	14	13
Dolerite	2.95	0.4	10	9
Granite	2.64	0.8	17	20
Micro-granite	2.65	0.5	12	14
Hornfels	2.81	0.5	15	11
Quartzite	2.63	1.8	20	18
Limestone	2.69	0.5	14	20
Greywacke	2.72	0.5	10	12

(After Bells, 2007)

The range of specific gravity required for pavement aggregate was earlier proposed by Matthew (2010) to be between 2.50 and 2.90. Similarly, Ugbe (2020) recommended that $SG > 2.55$ for heavy construction work. This value is supported by every rock sample from the research region. The values' consistency indicates that the research area's rock aggregates are appropriate for a variety of building projects.

2.2 Rocks' Engineering Properties

Engineering attributes of rocks are the physical properties they show when used in concrete with cement, sand, and water. These properties determine how the rocks behave and perform in civil engineering structures like buildings, embankments, retaining walls, and pavements. The engineering characteristics of the rocks examined in this research include the abrasion resistance, known as the Los Angeles Abrasion Value (LA AV (%)), the impact resistance, known as the Aggregate Impact Value (%), and the crushing resistance, known as the Aggregate Crushing Value, evaluated in percentage (%). The relative resistance of an aggregate to crushing under compressive pressures is measured by the Aggregate Crushing Value (ACV). The necessary strength to withstand

crushing under traffic wheel stresses should be present in aggregates used in road building. Aggregates with low ACV values are often selected for pavement constructions since weak aggregates would adversely influence the stability of the pavement structure.

The engineering characteristics of rocks are valued in Table 5. The Aggregate Crushing Value (ACV) values in the table vary from 15.6 to 20.7%. Basalt had the lowest value (average of 17.1%), while gabbro had the highest value (average of 20.7%). Granite has an average ACV of 19.7%, granodiorite has an average of 17.3%, and amphibolite rocks from the research region have an average ACV of 17.6%. In the sequence of basalt, granodiorite, amphibolite, granite, and gabbro, the examined rocks show diminishing resistance to crushing stress, which is increasing the value of ACV.

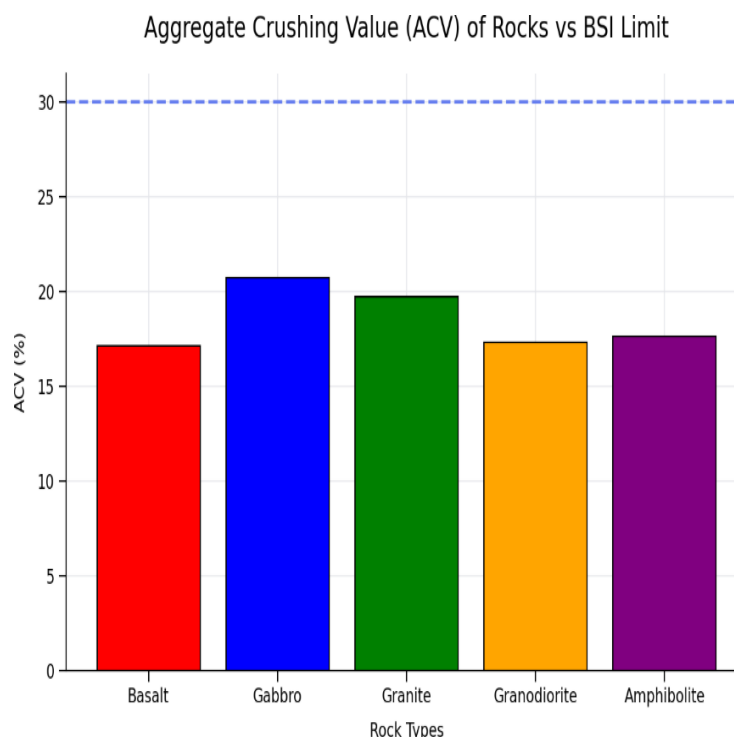


Figure 18: Bar chart showing ACV values of different rock types compared with the BSI (1990) and AASHTO (2001) standard limit of 30%.

Because of this, even though the basalt from the examined location is fine-grained, ACV judgements consider it to be a good engineering aggregate. However, as their values are within the permissible ranges suggested for civil engineering building, all of the rocks under examination are appropriate for any kind of construction. A limit of 30% was suggested by BSI (1990). According to AASHTO (2001), the ACV of aggregates used in construction should not be more than 30% for concrete used for roads and pavements, while 45% may be allowed for other constructions. According to Shetty (2005), the maximum value of ACV for wearing courses in pavement construction may be 45%. **Because the ACV is much less than 25%, it is evident that all of the aggregates produced from the research area's rocks are good building materials when compared to the established requirements.**

Nonetheless, it is possible to attribute the varying ACV values from various rock types to petrography and rock chemistry. Granite has more quartz and silica than granodiorite. This might be the cause of granite's somewhat lower ACV value when compared to granodiorite, despite the fact that both rocks are thought to be extremely similar geologically and from an engineering standpoint.

The next significant engineering test performed on the rock aggregate from the research region was the Aggregate Impact Value (AIV). AIV provides a relative assessment of the aggregate's ability to withstand abrupt shock or impact. Table 7 displays the range of AIV for aggregates made from rocks in the research region. Granites have a range of 10.30 to 20.85. Similar trends seen in ACV are also seen in AIV, where the engineering characteristics of the aggregates may be attributed to petrography and rock chemistry. The research area's AIV values match those reported by Bells (2007). According to Oyediran (2018), there is a numerical similarity between the values of AIV and ACV, indicating a comparable aggregate strength feature. Similarly, Al-Harathi (2001) found a large positive association between compressive strength and AIV/ACV. Since the examined rocks

had better impact resistance and lower AIV values, it can be assumed that their compressive strength would be quite high. According to ISRM (1989) and BSI (1990) regulations, the aggregate impact value for aggregates used in concrete—aside from wearing surfaces—must not exceed 45% by weight, and for concrete used for wearing surfaces, it must not exceed 30% by weight. According to AASHTO (2001), the AIV of rocks used as aggregates in road building must be less than 35%. From an engineering perspective, it may be concluded that the rocks are viable building materials since all of the analysed samples' AIV values fall below the maximum allowable ranges.

Table 6: Aggregate Strength Classification of aggregate based on AIV

Class	AIV (%)	Quality of aggregate
A	< 10	Exceptionally Strong
B	10 – 20	Strong
C	20 – 30	Satisfactory for road surfacing
D	>35	Weak for road surfacing

(after Thuro and Plinninger (2001))

The rock samples may be categorised as strong (Class B) with values between 10 and 20% using Thuro and Plinnigers' (2001) Classification Scheme, which is shown in TABLE 7. They may thus be used for any kind of civil building. One of the key engineering characteristics of rocks acquired from the research region is the Los Angeles Abrasion Value. These figures are from the Los Angeles Abrasion Test, which gauges an aggregate's ability to withstand wear and tyre polishing under heavy traffic. Better building aggregates are indicated by lower LAAV values. According to the current research, the average range of LAAV is between 20.9 and 24%. Granite has an average value of 24%, while granodiorite has the lowest value of 20.9%. Basalt and gabbro have average LAAV values of 21.3% and 23%, respectively, but amphibolites have an average of 23.4%. All of the rock samples under study had LAAV levels below the ASTM-recommended maximum allowable range of 35% (2001). According to Shetty (2005), LAAV values should not exceed 30% for wearing courses and 50% for concrete other than wearing surfaces. The maximum allowable LAAV values for various pavement types were specified by BSI (1990). This is seen in Table 8. Any engineering building activity is prohibited if the LAAV value is more than 60%.

Table 7: Los Angeles Abrasion Values for different pavement types

S/N	Types of Pavements	Maximum permissible abrasion value (%)
1	Water bound Macadam subbase course	60
2	WBM base course with bituminous surfacing	50
3	Bituminous Bound Macadam	50
4	WBM surfacing course	40
5	Bituminous penetrating Macadam	40
6	Bituminous surface dressing, cement concrete surface course	35
7	Bituminous concrete surface course	30

After BSI (1990)

2.3 Water Bound Macadam (WAM)

Swemgba et al (2026) in their research examined the LAAV of crystalline rocks in the Oban massif analytically and reviewed that, Amphibolites exhibits relatively poor resistance to abrasion (high LAAV) may potentially be responsible for its low quartz to feldspar ratio. When utilized in pavement construction, quartz, a more resilient mineral with a greater modal content in a rock, tends to make the rock more resilient to the polishing activities of car tires.

However, it can be safely assumed that these rocks can be used for all pavement types, including commercial roads, airfield runways, bridges, buildings and all other engineering constructions, since the values obtained from all samples show excellent results when compared with codes and standards. The LAAV of basalt rocks from the studied region is quite significant. Their poor quartz to feldspar ratio is the reason for the low value. This implies that the research area's basalt may be used for building and commercial purposes. Because the cost of

transportation and logistics for moving materials from far-off quarries would be much lower, this would lower the area's building costs.

Comparing the Study Area's Index and Engineering Properties with those of other Areas The engineering behavior and index properties of the crystalline basement rocks from the research region were compared to those of other geologic provinces. This was done to assess how geology affects the engineering behavior of rocks. This is seen in Table 9.

Table 8: Comparison of average index and engineering properties of aggregates from the study area with crystalline rocks in other locations of the world

	A	B	C	D	E
Density (g/cm ³)	2.56	2.55	NS	2.43	NS
Water Absorption Capacity (%)	0.53	0.54	0.58	0.29	0.87
Specific Gravity	2.67	NS	2.7	2.49	2.64
Aggregate Crushing Value ACV (%)	18.54	26	27.02	16.6	26
Aggregate Impact value AIV (%)	14.1	19	10.88	18.6	18
Los Angeles Abrasion Value LAAV (%)	22.52	22	26.2	NS	31
NS	-	Not Specified			
A	-	Present study			
B	-	Bamenda Massif, Southeastern Nigeria (Ndukauba & Akaha, 2012)			
C	-	Iyuku granite, Southwestern Nigerian (Ugbe, 2020)			
D	-	Precambrian rocks from South western Nigeria (Oyediran & Foghi, 2018)			
E	-	Rais Goth Crusher, Karachi, Pakistan (Zaidi <i>et al.</i> , 2008)			

The current study's findings were compared to those of the Bansara area of Bamenda Massif, Southeastern Nigeria, as reported by Ndukauba & Akaha (2012), Iyuku granite, Southwestern Nigeria, as reported by Ugbe (2020), Precambrian basement rocks, Southwestern Nigeria, as reported by Oyediran and Foghi (2018), and the Rais Goth Crusher, Karachi, Pakistan, as reported by Zaidi *et al.* (2008).

The basement rocks from the Bansara area of the Bamenda Massif in southeast Nigeria, as described by Ndukauba & Akaha (2012), and those from the southwestern region of Nigeria were consistently compared to the current research area. These geographic provinces' comparable orogenic occurrences, evolutionary history, and geology are likely the causes of this regularity (Ekwueme, 2003). In some instances, aggregate from the research area was shown to have marginally superior engineering attributes as building materials when compared to aggregate resources from other places. Examples include the comparison with Wisconsin Aggregate Resources, Wisconsin, USA (Willianson, 2005) and Rais Goth Crusher, Karachi, Pakistan (Zaidi *et al.*, 2008). This demonstrates and validates Nigeria's abundance of natural resources. The nation will grow quickly if the rock riches are properly explored and exploited.

According to **Hartley (1974)**, the data from the study area and Bamenda Massif (Nduka Uba & Akaha, 2012) in Southeastern Nigeria concur that geology has a significant impact on the physical and engineering characteristics of aggregates.

2.4 Geomechanical Assessment

Rock Mechanics is an applied discipline that studies the characteristics of rocks and the unique approach needed to construct rock-related engineering schemes. The strength, existence, kind, and direction of discontinuities, Rock Quality Designation (RQD), Poisson ratio, young modulus, drillability, and cuttability are some of the mechanical characteristics of rockmass. A few of these attributes are derived. Nonetheless, the majority of the mentioned characteristics have to do with the strength of the rocks as well as the existence and kind of discontinuities. While strength may be evaluated both in the field and in the lab, the existence and kind of discontinuities can only be determined in the field.

Strength measures, such as uniaxial compressive strength, Schmidt Hammer Rebound number point load index, and tensile strength, are the rock mechanical qualities of importance that were carried out since the current investigations included both field exercise and laboratory work.

The L-type Schmidt Hammer was used to measure the rocks' in-situ field strength, while the uniaxial compressive test and the Laboratory Schmidt Hammer Test are two laboratory strength tests. The geomechanical test results for the rocks in my research region are shown in Table 9.

Table 9: Mechanical properties of rocks from the study area

Sample No.	Rock Type	Uniaxial Compressive Strength UCS (MPa)	Mean Hammer SHR (Insitu)	Schmidt Rebound SHR (Lab)
M ₁	Amphibolite	114	40	30
M ₂	Amphibolite	112	34	32
M ₃	Granite	138	39	37
M ₄	Granite	129	37	35
M ₅	Basalt	156	42	38
M ₆	Basalt	142	44	39
M ₇	Basalt	138	44	40
M ₈	Basalt	155	46	42
M ₉	Gabbro	118	38	32
M ¹⁰	Gabbro	120	37	34
M11	Granodiorite	189	52	50
M12	Granodiorite	186	50	48

The uniaxial compressive strength (UCS) is one of the most important metrics used to assess the mechanical characteristics of rocks and categorise them. It is the most widely used metric for assessing slope stability and classifying rock masses. It is also a crucial factor in predicting the cuttability and drillability of rocks used in tunnelling.

According to Thuro (1997), determining the UCS of rocks is essential for various rock-related engineering projects, such as storage repositories, subterranean caverns, and dams. The rocks' uniaxial compressive strengths (UCS) vary from 112 MPa in amphibolites to 189 MPa in granodiorite. According to the average UCS value shown in Table 10, amphibolites have the lowest UCS value, followed by gabbro, granite, and basalt, with granodiorite having the highest. Granodiorite > Basalt > Granite > Gabbro > Amphibolite is the decreasing order of the UCS of rocks from the studied region. Rocks from the research region were categorised using the Uniaxial Compressive Strength (UCS) classification method proposed by Broch and Franklin (1972) (Table 9). According to the chart, the assessed rocks fall into classes A and B, which are high strength (other rock types) and very high strength (granodiorites), respectively. Because of this, the rocks may be used for building.

Additionally, this categorisation agrees with those published by ISRM (1979a), IAEG (1981), and Anon (1981). The high silica concentration in almost all of the rock samples from the research region is responsible for the high UCS values, with the exception of basalt, which has a high strength due to its fine grains and compact structure. Schmidt Hammer is another tool for figuring out a rock's mechanical strength. This is among the most effective and economical ways to determine a rock's UCS. It may be carried out on representative samples in the lab as well as in-situ (in the field).

Table 10: Classification of rock strength properties using UCS

Class	Uniaxial Compressive Strength (UCS) MPa	Description
A	> 160	Extremely high strength
B	50 – 160	Very high strength
C	15 – 50	High strength
D	5 – 15	Medium Strength
E	1.5 – 5	Low Strength
F	0.5 – 1.5	Very Low Strength
G	< 0.5	Extremely Low Strength

After Broch and Franklin (1972)

Both in the field (in-situ) and in the lab, the Schmidt Hammer Rebound value (SHR) was determined using a L type Schmidt Hammer in compliance with ASTM (2001).

About 16–20 tests were conducted at a time in accordance with the test specification and protocol, and the results were shown in ascending order of magnitude. As recommended by Oyediran and Foghi (2018), the

mean of the top 50% of the data was recorded as the Schmidt Hammer number both in-situ and in the lab, while the bottom 50% of the results were discarded. A critical observation from Table 10 displays the SHR from both the field and the lab. The tendency is consistent with the findings from the uniaxial testing apparatus. Granodiorite had the highest SHR number, followed by granite, gabbro, and basalt. Amphibolite had the lowest value.

A strong coefficient of correlation of $r^2 = 0.8562$ is obtained from a regression plot between the laboratory SHR and field SHR (Figure 19). This sample equipment's dependability in both the field and the lab is shown by its excellent positive correlation coefficient.

Additionally, there is a positive correlation coefficient between the in-situ SHR and the UCS from the laboratory compression testing apparatus (Figure 20). The r^2 is 0.722. This high r^2 value indicates a strong correlation between UCS and field-obtained SHR values. It is recommended that this equipment be easily used for non-destructive tests to obtain the Uniaxial Compressive Strength (UCS) of the rocks directly at the field, especially at the early stages of investigation of mechanical properties of rocks, given that the Schmidt Hammer is a small, straightforward, and user-friendly piece of equipment in the laboratory and the cost-benefit implications associated with its application compared to compression testing machines.

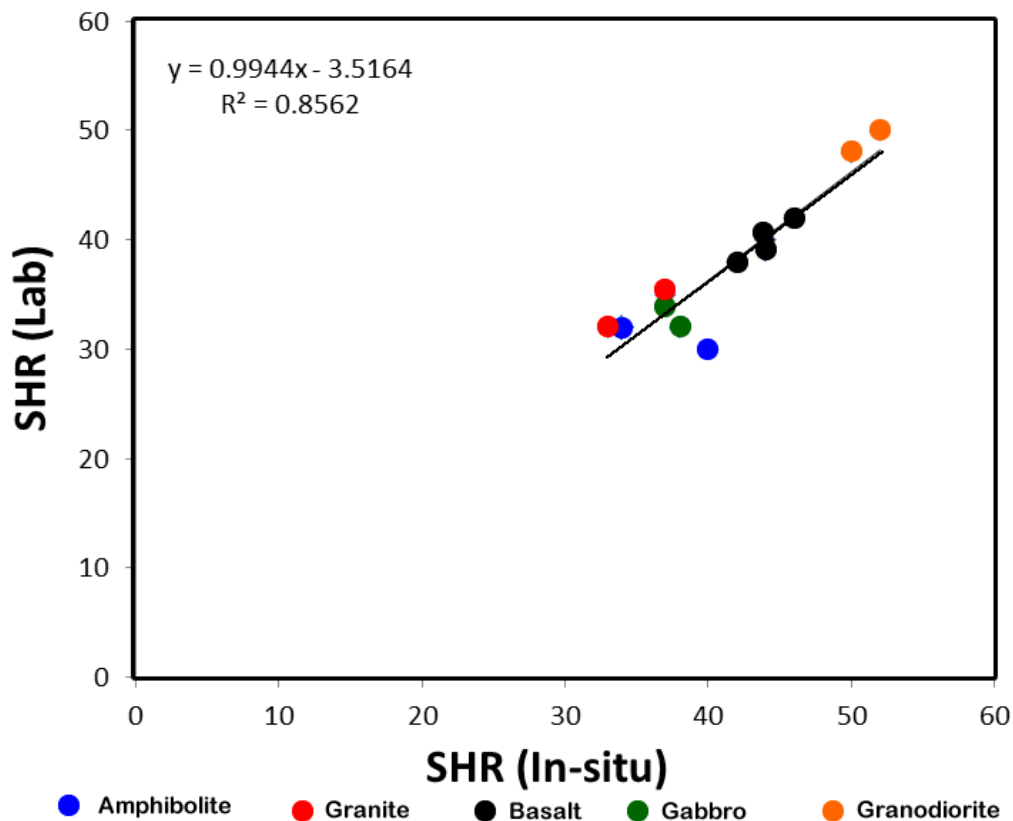


Figure 19: Regression plot of laboratory SHR vs field(in-situ) SHR

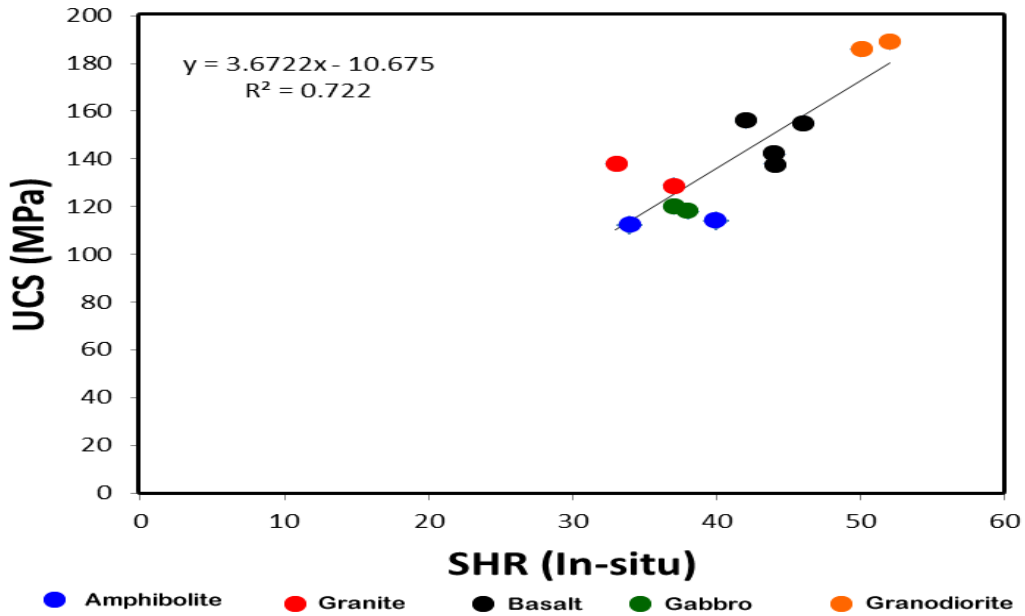


Figure 20: regression plot of UCS vs field(in-situ) SHR

A regression plot of specific gravity (SG) using the SHR and uniaxial compressive strength (UCS) is shown in Figure 20. This suggests that rocks with greater specific gravity also have higher UCS values. A similar pattern to that shown in Figure 19 is seen in Figure 20, where the N-values derived from the Schmidt Hammer Rebound were substituted for the UCS acquired in the lab. Additionally, a significant correlation between UCS and SHR was noted. As previously documented by **Kahram (1996)**, **Yiimaz and Sendir (2002)**, and **Kilic and Teymen (2008)**, this demonstrates that the Schmidt Hammer, a small, portable, and user-friendly instrument, may be easily used in the field or the lab to get the mechanical strength of rocks with great accuracy.

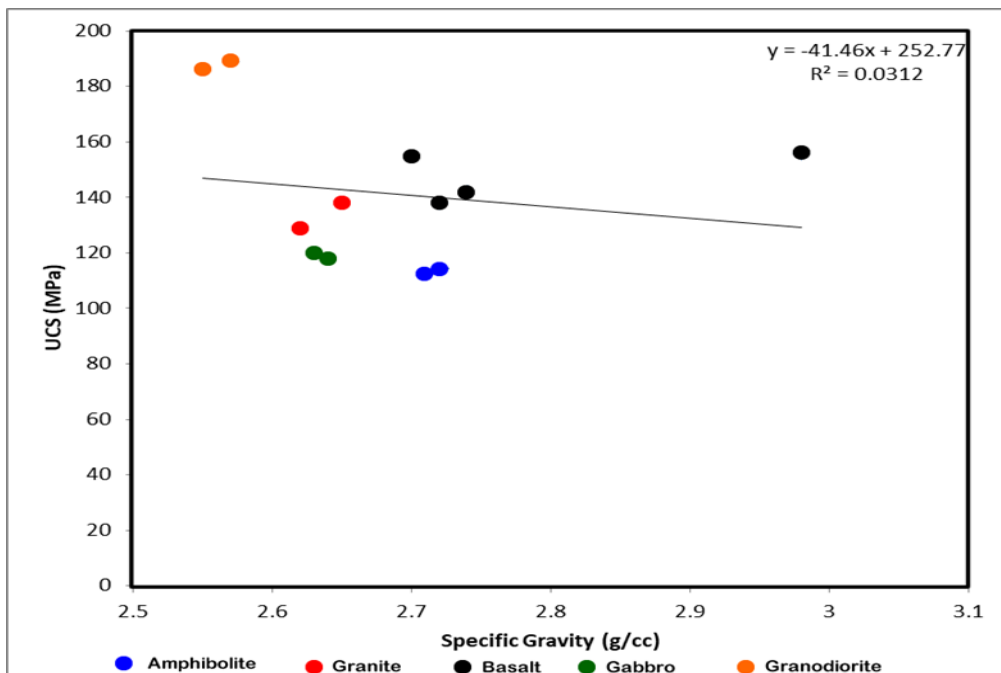


Figure 21: Regression plot of UCS vs Specific gravity

Although the r^2 value is modest, a regression plot of AIV vs. ACV (Figure 22) and ACV vs. LAAV (Figure 23) demonstrates a favourable association. The fact that a variety of rock kinds were employed might be the cause of the low value. This further demonstrates that civil engineers should be discouraged from using the term "granitic rocks" to refer to basement rocks for construction purposes because each type of rock will have a different mechanical behaviour due to its distinct chemistry, petrographic characteristics, and mineral assemblage. Similar

rock kinds will show stronger association, according to an observation of these plots (Figure 22). This is in line with the findings of Ugbe (2020) on Iyuku Granites ($r^2 = 0.9$). Because the AIV test process can be performed without an electrical power source, it is easier and less costly to do. As a result, it is highly recommended for use in forecasting the ACV of rocks.

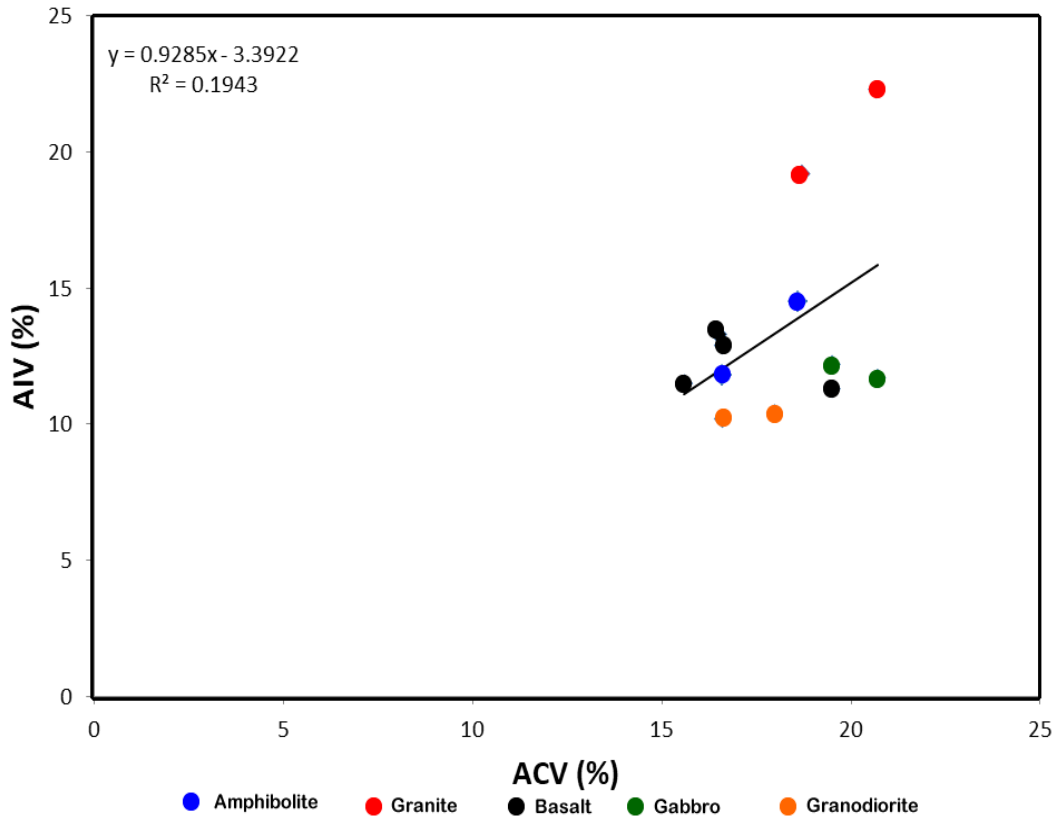


Figure 22: Regression plot of AIV vs ACV

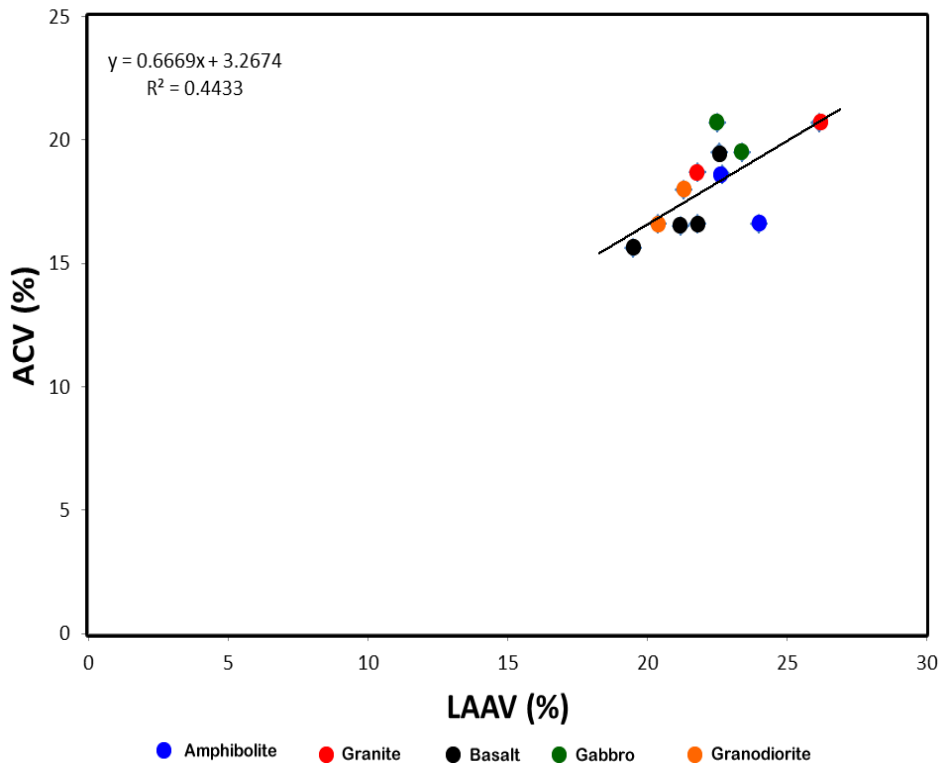


Figure 23: Regression plot of ACV vs LAAV

III. CONCLUSION

3.1 Summary and Conclusion

Density, Specific, Aggregate crushing, Aggregate Impact, Los Angeles Abrasion, and Uniaxial Compressive tests were among the noteworthy laboratory tests used to assess the mechanical, engineering, and physical characteristics of rocks. All of the rock samples are good geo-materials that may be used in any civil engineering project, according to the findings, which showed low values for WAC and weathering index and high values for AAV, LAAV, AIV, ACV, and UCS.

Given the Uniaxial Compressive Strength (UCS) test's comparatively important role in rock engineering projects and the strong correlation between UCS and the Schmidt Hammer Rebound, this straightforward instrument (Schmidt Hammer) can be used for a fast evaluation to suggest an initial value of UCS of rock quality in the study area and surrounding areas.

Water absorption capacity and specific gravity, ACV and AIV, were all shown to have significant statistical connections. These conclusions will direct the choice of rocks of a respectable calibre for use as building materials in civil engineering projects.

In conclusion, it is clear from all of the data that careful design and operation, geology alone, or laboratory and field testing alone will not result in the general safety of buildings constructed with and on rocks. However, if engineering geological mapping of rocks and rock materials is combined with cooperative investigations of petrography and rock chemistry, it is feasible to anticipate mechanical behaviour of rocks in a reasonable way. Preparing all rock and soil descriptions in an understandable manner for engineers is a helpful and recommended initial step.

3.2 Suggestions

The following suggestions have been made in light of the research, findings, and interpretations.

1. Although granites and granodiorites are superior building materials than basaltic rocks, rocks from the research region may be used for construction.
2. More study is required to determine how rock grain sizes affect crystalline rocks' strength, quality, and resistance.
3. There should be ongoing geological engineering and mapping of the Oban Massif and its surroundings as well as other basement complexes across the nation. The results of these studies will provide conveniently accessible knowledge about the mechanics of these rocks, which may be simply retrieved for the aim of enhancing engineering construction performance and environmental safety.
4. An engineering geologist or rock mechanic who is knowledgeable about the general characteristics of rock and rock mass should contribute to all civil engineering plans. This information may be derived from integrated studies on the behaviour of rocks in many geological fields.
5. To forecast the mechanical strength of rocks, cooperative study with different disciplines should be used. During the engineering site investigation, this forecast may be included in the desk research.
6. Using a basic field instrument, such as the Schmidt Hammer, may enhance environmental safety and save laboratory testing costs, particularly in the early phases of an inquiry. This will meet the fundamental engineering principles of economy and safety.
7. More investigation should be done into the usage of basaltic rocks from the Ikom region for ceramics and glass. Additionally, as the aggregates may be utilised as great geomaterials substitutes for engineering building, private investors should be encouraged to develop quarries and mine basalts from Ikom. This will result in fewer engineering projects being built in and around the region.

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