

Assessment of Geomechanical Characterization of Limestone in Yalo Community, Bauchi State, Nigeria for Engineering and Construction Applications

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Abstract: The Geomechanical characterization of limestone in Bauchi state, Nigeria for Engineering and construction applications was carried out with a view to determine the major oxides composition and evaluate both the physical and mechanical properties such as moisture content, dry density, point load index, uniaxial compressive strength and tensile strength. Five representative samples of the limestone were investigated for major oxides composition analysis which shows that the limestone is pure with high percentage of CaO with average of 43.24% while other oxides have a low concentration. The physical properties such as moisture content and dry density index value with average value of 4% and 2.44g/cm³ respectively are with acceptable range when compared with international standard such as AASHTO, ASTM, BS and ISRM. The mechanical properties value index such as point load, uniaxial compressive strength and tensile strength also falls within moderate to high strength when compare with standard like ISRM with average of 3 MPa, 90MPa, and 5.7MPa respectively. From all the evaluation base on the properties of the limestone, it shows that it is good raw material for cement and also good material in Engineering and construction works. The results of this study demonstrate that the limestone from Bauchi State is not only an excellent raw material for cement production but also possesses favorable characteristics for various engineering and construction applications. This research contributes valuable insights into the properties of local limestone resources, promoting their sustainable use in construction practices and supporting the development of infrastructure in Nigeria. Through rigorous evaluation and analysis, this study highlights the importance of characterizing geological materials to optimize their application in engineering projects, thereby enhancing the quality and sustainability of construction in the region.

Keywords: Limestone, Geomechanical Characterization, Moisture Content, Dry Density, Point Load Index, Uniaxial Compressive Strength (UCS), Tensile Strength, Engineering Properties, Rock Mechanics, Sustainable Construction, ISRM, ASTM, AASHTO, British Standards (BS).

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I. INTRODUCTION

Limestone is one of the most widely distributed sedimentary rocks on earth, primarily composed of calcium carbonate (CaCO₃) and formed through the accumulation of organic remains or through chemical precipitation. Its unique properties have made it a fundamental material in various engineering and construction applications, including cement production, road construction, and as a foundation material for buildings and other infrastructures. In Nigeria, limestone is abundant, particularly in regions such as Bauchi State,

where its geological formations are significant to both local economies and engineering practices. The importance of understanding the geomechanical properties of limestone cannot be overstated, especially in regions where construction activities are prevalent. Geomechanical characterization involves assessing the physical and mechanical properties of geological materials to determine their behavior under various loading conditions. These properties include point load, moisture content, and dry density. Such parameters are essential for engineers to evaluate the suitability of limestone for specific applications,

ensuring the stability and longevity of structures built upon it (Adeleke *et al.*, 2020; Olayinka *et al.*, 2019). In Bauchi State, the geological landscape is characterized by extensive limestone deposits that have been subjected to various geological processes over millions of years. These processes can influence the mineral composition, texture, and overall mechanical behavior of the limestone. Previous studies have indicated that factors such as weathering, mineral impurities, and the presence of fractures can significantly affect the strength and durability of limestone (Musa *et al.*, 2021). Understanding these variations is crucial for engineering applications, particularly in regions prone to geological hazards such as landslides or subsidence. The geomechanical properties of limestone in Bauchi State are particularly relevant given the ongoing infrastructure development in Nigeria. The demand for durable and reliable construction materials has increased with urbanization and economic growth. As a result, engineers and geologists must possess comprehensive knowledge about the local geological conditions to make informed decisions regarding material selection and site development (Ojo *et al.*, 2018). Furthermore, with the increasing emphasis on sustainable development, it is essential to utilize local resources efficiently while minimizing environmental impacts. Several studies have investigated the geomechanical properties of limestone in different regions of Nigeria, providing valuable insights into its potential applications. For instance, research conducted in southwestern Nigeria highlighted the significant variations in mechanical properties due to differences in mineral composition and environmental conditions (Adeleke *et al.*, 2020). Similarly, investigations in northern Nigeria revealed that the geotechnical characteristics of limestone can vary widely based on geographical location and geological history (Olayinka *et al.*, 2019). However, there is a notable gap in the literature regarding the specific geomechanical characterization of limestone in Bauchi State. necessary to provide detailed insights into the suitability of local limestone for various structural applications. By assessing its physical and mechanical properties, the research will support the construction industry, promote sustainable use of local resources, enhance economic development, and guide policy formulation for optimal utilization. This ensures safety, cost-efficiency, and environmental sustainability in engineering practices.

II. MATERIALS AND METHODS

Materials used for this study include; Geographical Positioning System (GPS), Field notebook, hammer, sample bags and a digital camera. Each of these materials listed above performs a unique function in the field. The geographical positioning system (GPS) was used to take geographical coordinates at each location, the field notebook was used to record observations at each location, Hammer was used to take sample, the sample bag was used to carry the sample and the digital camera was also used to take pictures of relevant information in the field.

➤ List of Plates



Plate 1 Showing Area / Coordinate Sample was Pick



Plate 2 Showing Area / Coordinate Sample was Pick.



Plate 3 Showing Area / Coordinate Sample was Pick.



Plate 4 Showing Area / Coordinate Sample was Pick.



Plate 5 Showing Area / Coordinate Sample was Pick.



Plate 6. Showing Me in the Field Picking Sample.

➤ *Methods*

• *Field Mapping*

Geological field mapping was undertaken in order to collect, identify and study the field occurrences cum structural relationship of all the rock types present in the study area. Fresh and un-weathered rock samples were broken for hand specimen examination. Preliminary observation and identification of each constituent mineral were carried out using magnifying lens.

➤ *Laboratory Analysis (The Atomic Absorption Spectrometry)*

In the laboratory, samples were analysed using atomic absorption spectrometry (AAS) to determine the concentration of major elemental oxides and common trace elements. Major elemental oxides such as SiO_2 , Al_2O_3 , K_2O , Na_2O , CaO , MgO , Fe_2O_3 , P_2O_5 and LOI were obtained.

• *Sample Preparation (AAS)*

Samples were dissolved with excess HCl, and oxidized with H_2SO_4 followed by combustion in the oxygen bomb, evaporate to dryness and was also filtered to avoid clogging. Acetylene- Air for temperatures of 2100-2400°C was used.

➤ *Geotechnical Analysis*

• *Moisture Content*

The Oven-drying method was employed for the laboratory test to determine the natural moisture content as adopted by British Standard. Oven - Drying Method (Standard Method). This is a B.S. method in which the rock sample is been dried in an oven at a temperature range of 105°C to 110°C. It is the most popular, simple and most accurate method.

➤ *Apparatus*

- Oven (thermostatically controlled, and capable of operating to $105 \pm 5^\circ\text{C}$)
- Tongs
- Weighing Balance (to the required sensitivity)
- Container (corrosion-resistant tins or trays)
- Undisturbed rock sample Test Procedure
- ✓ One clean container with the lid (if fitted) was obtained and its mass in grams was recorded (m_1) together with the container number.
- ✓ The sample of wet rock was crumbled and placed in the container. The container with the lid on was weighed in grams (m_2).
- ✓ The lid was removed and both lid and container were placed in the oven. The sample was then dried in a thermostatically controlled drying oven which was maintained at a temperature of $105 \pm 5^\circ\text{C}$ for period of 16 to 24 hours.
- ✓ The container was then removed from the oven, placed in a desiccator and allowed to cool.

After cooling, the container plus dry sample was

weighed in grams (m^3). Calculation and expression of results

Data collected in this test included the following.

Mass of Container, M. (g)

Mass of container and wet sample,

Mows Mass of container and oven-dried sample,

Mos Mass of water ($M_w - M_{ows} - M_{cs}$)

Mass of solid particles ($M_s = M_{os} - M_c$) Calculate the water content as follows:

$$\text{Moisture content, } w = \frac{\text{Mass of moisture } (M_w) \times 100\%}{\text{Mass of dry sample } (M_s)}$$

$$= \frac{(\text{mass of container+wet sample}) - (\text{mass of container+dry sample})}{(\text{mass of container+dry sample}) - (\text{mass of container})} \times 100 \quad (1)$$

- *Dry Density*

Equipment and Materials that was used includes;

- ✓ Limestone Sample: A representative sample of limestone.
- ✓ Weighing Balance: A balance capable of measuring accurately to 0.01 g or better.
- ✓ Graduated Cylinder: For measuring the volume of the limestone sample.
- ✓ Oven: Set at 105°C to 110°C for drying the sample.
- ✓ Desiccator: To cool the dried sample without absorbing moisture.
- ✓ Sieve (if necessary): To obtain a specific particle size, if required by the testing standard.

- *Sample Preparation*

A representative sample of limestone was crushed and sieved; this is to obtain a specific particle size (commonly passing through a 2 mm sieve). The prepared limestone sample was weighed using the balance. Record this weight as $W_{(wet)}$. The limestone sample was placed in an oven set at a temperature of 105°C to 110°C, and the sample was allowed to dry for a minimum of 24 hours or until it reaches a constant weight (no further weight change occurs). After drying, the sample were removed from the oven and place it in a desiccator to cool down.

Once cooled, the dry sample was weighed using the balance. Record this weight as $W_{(dry)}$.

Measure the Volume of the Sample. Fill the graduated cylinder with water to a known level (record this volume). Submerge the dry limestone sample in the water and record the new water level. Calculate the volume of the limestone by subtracting the initial water level from the new water level. Calculate Dry Density, The dry density (ρ_d) can be calculated using the formula:

$$\rho_d = \frac{W_{dry}}{V} \quad (2)$$

Where:

$W_{(dry)}$ = weight of the dry limestone sample (in grams) V = volume of the limestone sample (in cubic centimeters).

- *Point Load Test*

Equipment and Materials Needed

- ✓ Rock Sample: A cylindrical or irregularly shaped limestone specimen.
- ✓ Point Load Test Apparatus: This typically consists of:
 - A loading frame or machine capable of applying a load.
 - A means of measuring the applied load (load cell or dial gauge).
 - Two-pointed loading jaws.
- ✓ Measuring Tools: Ruler or calliper for measuring dimensions.
- ✓ Safety Gear: Personal protective equipment (PPE) like gloves and safety glasses.

Steps to Carry Out the Point Load Test

- ✓ *Sample Preparation*

- Selection of the Sample: A representative limestone sample that is free from significant fractures, voids, or other defects.
- Shape the Sample: If necessary, prepare the sample into a suitable shape. The most common shapes are:
 - Cylindrical specimens with a diameter of about 50 mm to 100 mm.
 - Irregular specimens can also be used but should have a consistent size and shape.

- ✓ *Measure Dimensions*

- Measure the diameter (or equivalent dimensions) of the cylindrical specimen using a caliper.
- Record the dimensions accurately, as they will be needed for calculations.

- ✓ *Set Up the Testing Apparatus*

- Position the limestone sample in the point load testing apparatus.
- Ensure that the specimen is properly aligned between the loading jaws to avoid eccentric loading.

✓ *Apply Load*

- Gradually apply load to the specimen using the testing machine.
- Monitor the load applied continuously, and record the load at regular intervals or as it approaches failure.

✓ *Observe Failure*

- Continue applying load until the specimen fails. Failure is typically indicated by visible cracking or splitting of the rock.
- Record the maximum load applied at failure (P_{max}).

✓ *Calculate Point Load Strength*

- The point load strength (IS_{50}) was calculated using Equation 3:

$$IS_{50} = \frac{P_{max}}{D^2} \quad (3)$$

Where:

- IS_{50} = Point load strength (in MPa)
- P_{max} = Maximum load at failure (in Newtons)
- D = Diameter of the specimen (in mm)

➤ *Data Analysis*

The data collected from the laboratory tests were analysed using appropriate statistical techniques. The results were interpreted using EXCEL software and compared with relevant standards and specifications to assess the engineering properties of the rock samples.

III. RESULTS AND DISCUSSION

The results of the analysis carried out on the sample were presented and discussed both the geochemical and geomechanical properties of the samples.

Table 1 Major Oxides Composition

Oxide composition	Sample1 %	Sample 2 %	Sample 3 %	Sample 4 %	Sample 5 %	Range	Average
CaO	47.52	39.26	49.93	44.03	35.46	49.93 - 35.46	43.24
MgO	ND	5.89	1.12	1.27	8.07	8.07 – 1.12	4.0875
SiO ₂	2.40	13.14	1.80	0.52	11.06	13.14 – 0.52	5.804
Al ₂ O ₃	4.87	2.72	2.64	8.50	4.52	8.5 – 2.64	4.65
Fe ₂ O ₃	0.73	1.55	1.36	0.20	0.79	1.55 – 0.2	0.926
TiO ₂	ND	ND	NDD	ND	ND	ND	ND
Na ₂ O	0.03	0.31	0.42	0.02	0.08	0.42 – 0.02	0.172
K ₂ O	0.12	0.74	0.53	ND	0.29	0.74 – 0.12	0.42
Loss On Ignition (LOI)	41.70	35.13	42.20	43.84	38.58	43.84 – 35.13	40.29
Total	97.37	98.74	100	98.38	98.95	100 – 97	99.5895

➤ *Geochemical Analysis*

Table 1 shows the concentration of some selected major oxides analysis of limestone of the Yalo Community, Alkaleri LGA, Bauchi State. Collected for quality assessment. The analytical results of the samples show average CaO and MgO contents of 43.24wt% and 4.0875wt% with range of 49.93 - 35.46% and 8.07 – 1.12%. SiO₂ range from 13.14 to 0.52% with an average of 5.804%, Al₂O₃ range from 8.5 to 2.64% with an average of 4.65%, Fe₂O₃ range from 1.55 to 0.2% with an average 0.926%, Na₂O range from 0.42 to 0.02% with an average of 0.172%, TiO₂ was not detected in all the samples, K₂O range from 0.74 to 0.12% with an average of 0.42% and LOI (CO₂) range from 43.84 to 35.13% with an average of 40.29%.

The relatively high level of CaO and low values of silica and MgO, Table 1. show a high degree of purity of the limestone hence its suitability as raw material for cement. The CaO compares favourably with that of Olade (1988) put at

45.2% but far lower than that of Sagamu, Ewekoro and Ibeshe having mean values of 89.2%, 80.3% and 75.7% respectively, Akinmosin *et al* (2005). Silica concentrations of Nkalagu is low (average of 5.802%) compared with other limestone deposit in Nigeria; such as Ewekoro (19.9%), Igunmale (13.9%), Sokoto (11.3%), Olade (1988), but almost at par with that of Sagamu, Ewekoro and Ibeshe with mean values of 5.7%, 8.7% and 14.8% respectively, Akinmosin *et al.* (2005).

➤ *Geomechanical Properties*

Aggregate possesses variety of physio mechanical properties which determine their suitability as a construction material. Quality of an aggregate is directly related to the source rock properties (Koukis, G. and Sabatakakis, N. (2007)). The results obtained from the physical and mechanical analyses of the values of crushed limestones are presented in Tables 2.

Table 2 Geomechanical Properties of the Sample Results

Sample	Dry density(g/cm ³)	Moisture content (%)	Point Load(MPa)	Uniaxial Compressive strength (MPa)	Tensile Strength (MPa)
Sample 1	2.1	4	3	100	4.5
Sample 2	2.5	5	5	125	7.5

Sample 3	2.2	3	4	75	6
Sample 4	2.4	3	3	75	4.5
Sample 5	3.0	5	4	75	6
Average	2.44	4	3.8	90	5.7

- *Moisture Content*

Analyzing the moisture content of the five samples reveals a significant range, from 3% in Sample 3-5, to 5% in Sample 2 (Table 2). This variation highlights the importance of individual sampling location when evaluating soil suitability for construction purposes.

Comparing these values to relevant standardized limits helps assess their initial compatibility with various construction applications. ASTM C33, for instance, specifies a maximum moisture content of 5% for fine aggregates used in concrete mixtures (ASTM International, 2016). USCS Groups GP, GM, SW, and SM typically permit moisture contents up to 12% for use in embankments and subgrades (U.S. Department of Transportation, 2012). Similarly, AASHTO T99 specifies a maximum of 4% moisture content for compaction of subgrade soils in pavement construction (AASHTO, 2016). British Standard BS 60310 recommends a moisture content below 15% for compacted earth platforms for highways (British Standards Institution, 2004).

Based on these standards, Samples 1-5 clearly fall within acceptable ranges for various construction materials and applications. The low moisture content of Sample 3 and 4 suggests high permeability and potentially efficient drainage, but might necessitate additional wetting efforts during compaction to achieve optimal density. In contrast, Samples 2 and 5, with slightly higher moisture levels, possess potentially better workability during construction but may require improved drainage solutions to prevent saturation and stability issues.

However, Samples 2 and 5, exceeding the recommended moisture content limits in some standards, warrant further investigation. Their higher moisture levels suggest potentially lower shear strength and stability, possibly necessitating dewatering efforts or specific foundation design considerations to mitigate negative impacts on bearing capacity and settlement.

Therefore, while the initial analysis based on moisture content reveals promising potential for Samples 1,3 and 4. Samples 2 and 5 raise concerns that require further investigation. Considering the intended construction application and relevant standards is crucial when interpreting moisture content data. With a comprehensive understanding of individual sample properties and potential limitations, engineers can make informed decisions regarding soil selection, foundation design, and construction methodologies, ensuring the success and long-term performance of construction projects.

- *Dry Density*

Dry density is defined as a mass per unit volume. The mass of a unit volume of rock in its natural state is different

from the mass of the same volume of rock containing only its solid phase. The statistical calculation of volumetric weight is given in Table 2. Five specimens with different dimensions ($L \times W \times H$) of the limestone rocks from the study area were prepared by disc saw machine; then dried in oven at 105°C for 24 hr.

The results of dry density showing that the average value of dry density is 2.44 g/cm³ (Table 2), this indicate that samples have medium value of dry density (IQS, 1989). This range falls into the normal density category of aggregates (NF 1983). The dry density ranging between 2 - 3 g/cm³ can also be considered medium weight aggregate, and the samples which have dry density 2.6 g/cm³ are more suitable for aggregate (Zafir, N. and Majid, A. 2000).

- *Point Load Test*

Point load testing is used to determine rock strength indexes in geotechnical practice. The point load test apparatus and procedure enable economical testing of core or lump rock samples. The point load test (PLT) is an accepted rock mechanics testing procedure used for the calculation of a rock strength index. This index can be used to estimate other rock strength parameters like Tensile Strength and Uniaxial compressive strength. The PLT has been used in geotechnical analysis for over thirty years (ISRM, 1985). The point load strength index is obtained from the laboratory results (Tables 4.2) and varies from 3.0 MPa to 5.0 MPa for study area. With an average of 3.8 MPa, the strength classifications fall within the range of high strength class.

- *Tensile Strength*

The tensile strength of the rock samples was estimated based on the relationship suggested by Brook (1993) and ISRM (1989) which shows the general relationship between the point load strength (I_s) and the tensile strength (T_o) as expressed in equation 1 and the results presented in Tables 2.

$$T_o = 1.5I_s \quad (4)$$

The tensile strength, obtained from point load strength ranges from 4.5 MPa to 7.5 MPa with an average of 5.7 MPa. Which fall within the range of high strength class. (ISRM, 1989).

- *Uniaxial Compressive Strength*

The UCS is undoubtedly the geotechnical property that is most often quoted in rock engineering practice. It is widely understood as a rough index, which gives a first approximation of the range of issues that are likely to be encountered in a variety of engineering problems including roof support, pillar design, and excavation technique (ISRM, 1985.). For most coal mine design problems, a reasonable approximation of the UCS is sufficient. This is due in part to the high variability of UCS measurements. Moreover, the tests

are expensive, primarily because of the need to carefully prepare the specimens to ensure that their ends are parallel.

(ISRM, 1993.) Suggested that the uniaxial compressive strength can be estimated from the point load index using the relationship below.

$$UCS = k \cdot I_s \tag{5}$$

Where k is the conversion factor and it's a constant. In this work the $k = 25$ and the results is presented in the Table 2. the average value of (UCS) of the limestone is 95 MPa. According to the proposed strength classification of NZGS (Romana, M. and Vasarhelyi, B. 2007), the value of the limestone pointed out that, this sample is very strong.

➤ *Relationship UCS (Uniaxial Compressive Strength) and other Geomechanical Properties of the Limestone.*

The study deals with and discusses the results of a series of tests on this limestone to evaluate their potential as a construction material. Mutual relationships of parameters have been described by simple regression analysis.

Almost all the mechanical properties such as moisture content, point load, and Tensile strength shows a proportional relationship with the UCS as shown in figure (Fig. 1a – 1c) with good correlation of ($R^2=0.3125$, $R^2=0.2857$, $R^2=0.2857$) respectively. The inverse relationship between UCS and Dry density for the samples was shown in Figure 1d, also. With $R^2= 0.0307$. The results indicate that there is a strong significant correlation between the parameters of limestone samples to use as construction materials.

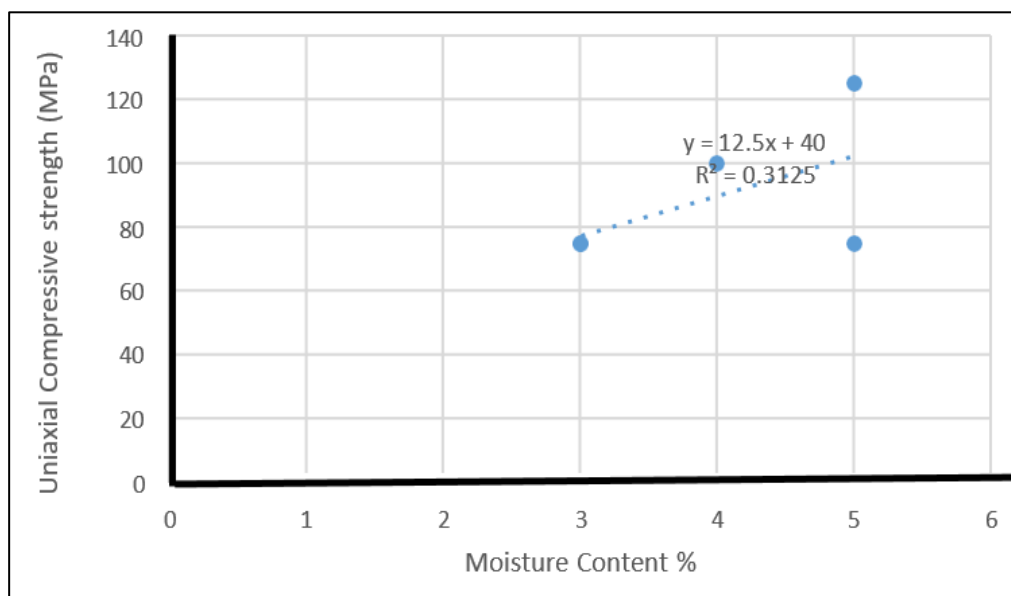


Fig 1a Relationship between UCS and Moisture content

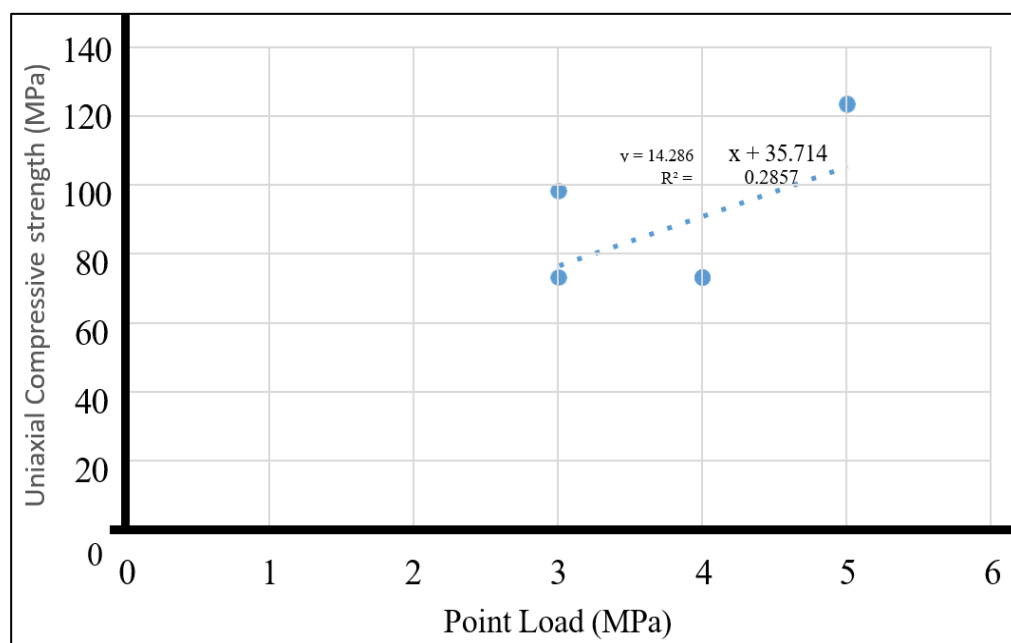


Fig 1b Relationship between UCS and Point Load

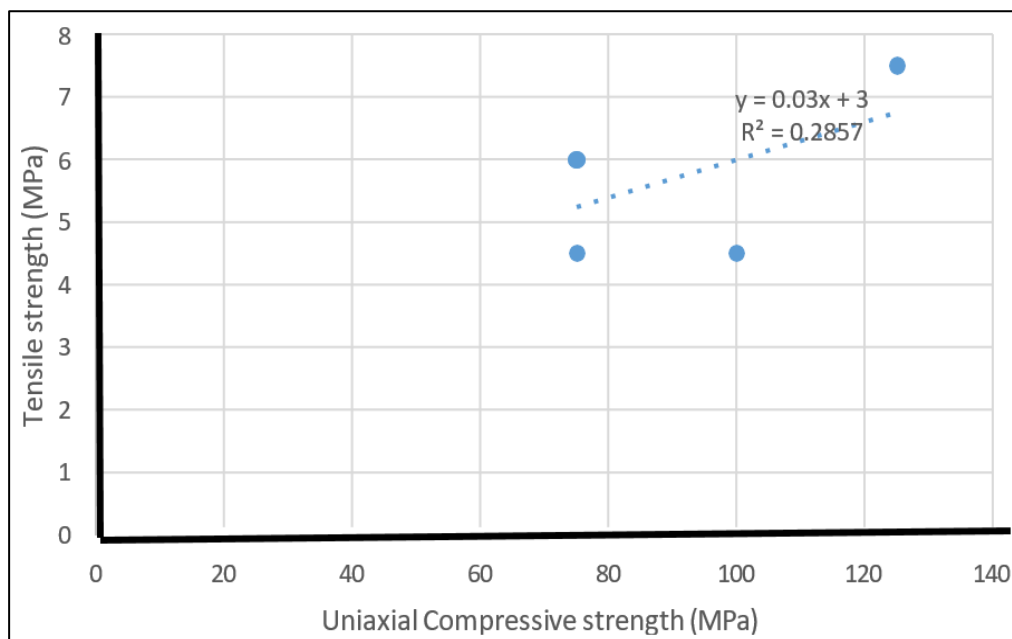


Fig 1c Relationship between UCS and Tensile Strength

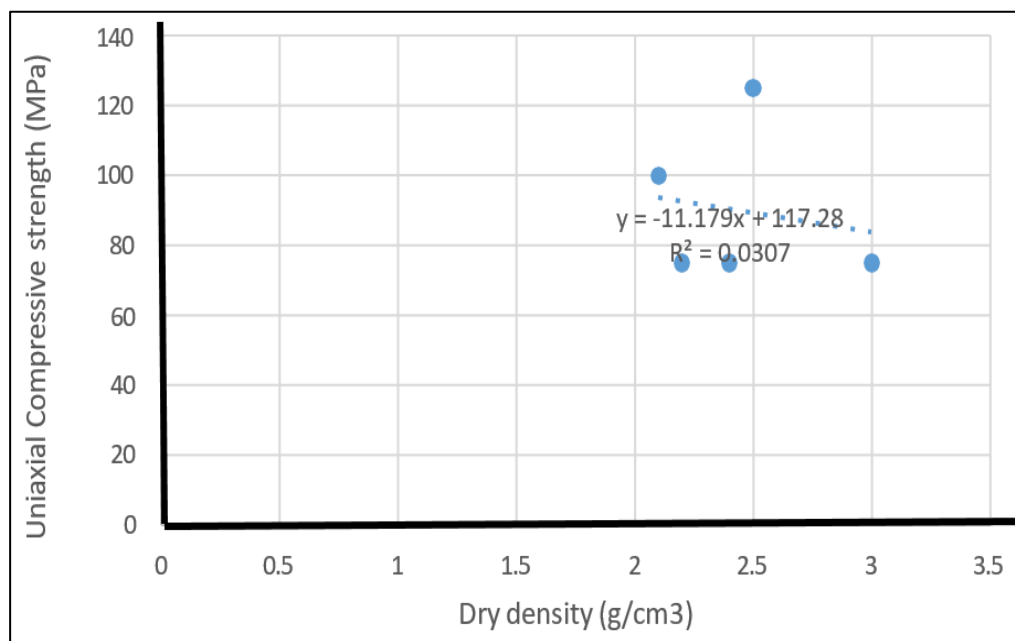


Fig 1d Relationship between UCS and Dry Density

IV. CONCLUSION

This project is carried out to determine the geochemical and geomechanical properties of limestone such as moisture content, dry density, point load and the estimated uniaxial compressive strength and tensile strength based on the major oxides composition of the limestone samples, with high percentage of CaO, it can be concluded that the limestone is pure hence its suitability as raw material for cement production. Based on geomechanical properties of the limestone, which its index value when compared with standards such as AASHTO, BS, ISRM falls within high strength aggregate for engineering and construction purposes.

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