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Engineering Properties of Some Basement Rocks of Nigeria as Aggregate in Civil Engineering Pavement Construction

Falowo Olumuyiwa Olusola

Department of Geology, University of Benin, Benin City, Edo State, Nigeria.
Email: solageo@yahoo.co.uk Tel: +2348025965896

Abstract

The engineering performance of construction materials is strongly related to their physical properties. Therefore in order to determine the suitability of the rock units in northern parts of Ondo State, Nigeria as aggregates for pavement construction, eight rock samples comprising porphyritic granite, granite, migmatite, granite gneiss, quartz schist, granodiorite, charnockite, and quartzite, were subjected to physical tests which include moisture content, dry density, porosity, specific gravity, aggregate impact value, aggregate crushing value, point load strength index, unconfined compressive strength, and shear strength. The tests were conducted in accordance to ASTM D2216 and ISRM-2386 standard test methods. The aggregate impact value of the samples ranges from 11.2 (Quartzite/granite gneiss) to 17.3 (Charnockite), while aggregate crushing value varies from 18.4 (Quartzite) to 25.2 (Charnockite). The water absorption of the rock units ranges between 0.27 and 0.82%, and porosity recorded 0.18 – 0.46%. Point load strength index, shear strength, and unconfined compressive strength of the samples ranges from 7.40 - 9.87, 60.5 – 92.6MPa, and 121.1 – 185.3 respectively. The values of AIV and ACV are within the standard specification value for road material, cement concrete pavement and wearing surfaces of 30% and 45% maximum. Therefore the rock units are very excellent as aggregate for road pavement construction and categorized as strong aggregate in terms of quality for road pavement. It is also observed that porosity and specific gravity are the major parameters that show strong positive correlations (≥0.5) with important geotechnical parameters such as shear strength, unconfined compressive strength, and point load strength index.

Keywords: Construction material, Aggregate, Pavement, Aggregate impact value, Aggregate crushing value, Point load strength index.

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Contents

Contribution of this paper to the literature
The present study was able contribute to the existing knowledge by providing some geological information and engineering properties of some basement rocks of Southwestern Nigeria, as aggregates in civil engineering construction especially pavements; since aggregates are principal materials in pavement construction which can take the form of either stabilized or unstabilized base or sub-base courses. The information is very crucial and pertinent to designing high quality roads in the study area. In addition the work would also be useful in selecting the rock types for quarry, for the production of aggregates for optimum use in sustainable highway construction.

1. Introduction

Rock is one of the geomaterial used in construction in form of concrete, aggregate, building stone, and armourstone [1-4]. The suitability of rock for any civil engineering construction work depends on its physical property [5] and this is one of the basic goals of rock mechanics: to provide useful information and methods for predicting failure strength and associated parameters such as strain to failure and the effect of porosity and elastic moduli [6]. For ages rocks have been used as a construction material because it's readily availability either in form of igneous, sedimentary, or metamorphic rock. Although rocks requires little energy for extraction and processing. Indeed, rock is used more or less as it is found except for the seasoning, shaping and dressing that is necessary before it is used for civil engineering construction purposes. However the volume of material that can be quarried; the ease with which it can be quarried [6] the wastage consequent upon quarrying; and the cost of transportation; as well as its appearance and physical properties [7, 8] are the determining factors whether a rock would re-worked as construction material. Also texture, appearance, porosity, durability [9-11] etc. are also desirable qualities of aggregates. Crushed rock is produced for a number of purposes, the chief of which are for concrete and road aggregate [12-14]. Approximately 75% of the volume of concrete consists of aggregate, therefore its properties have a significant influence on the engineering behaviour of concrete [12]. Aggregate is divided into coarse and fine types, the former usually consisting of rock material that is less than 40 mm and larger than 4 mm in size. The latter is obviously less than 4 mm. Fine types less than 75 mm should not exceed 10% by weight of the aggregate [12]; [15].

2. Literature Review

Aggregate constitutes the basic material for road construction and is quarried in the same way as aggregate for concrete [16, 17]. Because it forms the greater part of a road surface, aggregate has to bear the main stresses imposed by traffic, such as slow-crushing loads and rapid-impact loads, and has to resist wear. Therefore, the rock material used should be fresh and have high strength [12]; [18, 19]. In addition, the aggregate used in the wearing course should be able to resist the polishing action of the traffic. The properties of road aggregate are related to the texture and mineralogical composition of the rock from which it was derived. Most igneous and contact metamorphic rocks meet the requirements demanded of good roadstone [15]; [20]. On the other hand, many rocks of regional metamorphic origin are either cleaved or schistose and are therefore unsuitable for roadstone. This is because they tend to produce flaky particles when crushed. Such particles do not achieve good interlock and, consequently, impair the development of dense mixtures for surface dressing. The amount and type of cement and/or matrix material that bind grains together in a sedimentary rock influence roadstone performance. The shape of aggregate particles is an important property and is governed mainly by the fracture pattern within a rock mass. The surface texture of aggregate particles largely determines the strength of the bond between the cement and themselves. A rough surface creates a good bond, whereas a smooth surface does not.

Many researchers [21-24] have tremendously contributed to knowledge in the aspects of compositional features and petrotectonic significance of quartzite and quartz-schist. Studies on the compressive strength of artificial composite rock materials in relation to their moisture content in Malaysia [25] emphasized probable complex engineering challenges due to variation in the rock composition. Akpokodje [26] studied certain rock aggregates for the Nigerian Basement rocks. His findings show that the aggregates are good engineering materials based on both compressive strength and water absorption characteristics. Adebisi and Adeyemi [27] confirmed the exclusive sensitivity of gneisses in South-west Nigeria to moisture content among other properties. The present study tries to employ field disposition and more importantly, some basic physical/geotechnical properties of the rocks in northern part of Ondo, Southwestern Nigeria to elucidate further on their usefulness in civil engineering construction especially in the area of concreting, and aggregates in pavement construction.

3. Description of Study Area

The study area is located within the northern part of Ondo State, Nigeria Figure 1. The selected areas include Owo, Akoko, and Ose. These areas are located within longitudes 5°20´E and 6°10´E and latitudes 6°30´N and 7°40´N. The area is accessible through the Benin - Ifon highway, Abuja - Lokoja Highway and Ado-Akure highway. The study area has a topographical elevation varying from 40 m – 750 m above the sea level. The northern part of the study area is a rugged terrain (i.e. hilly) especially in Akoko area [28]. The annual rainfall ranges between 1000 and 1800 mm, with a mean annual rainfall of 1500 mm, and average wet days of about 100. The mean annual temperature is between 21°C and 33°C with mean temperature of 24°C and mean humidity of 80% [29].

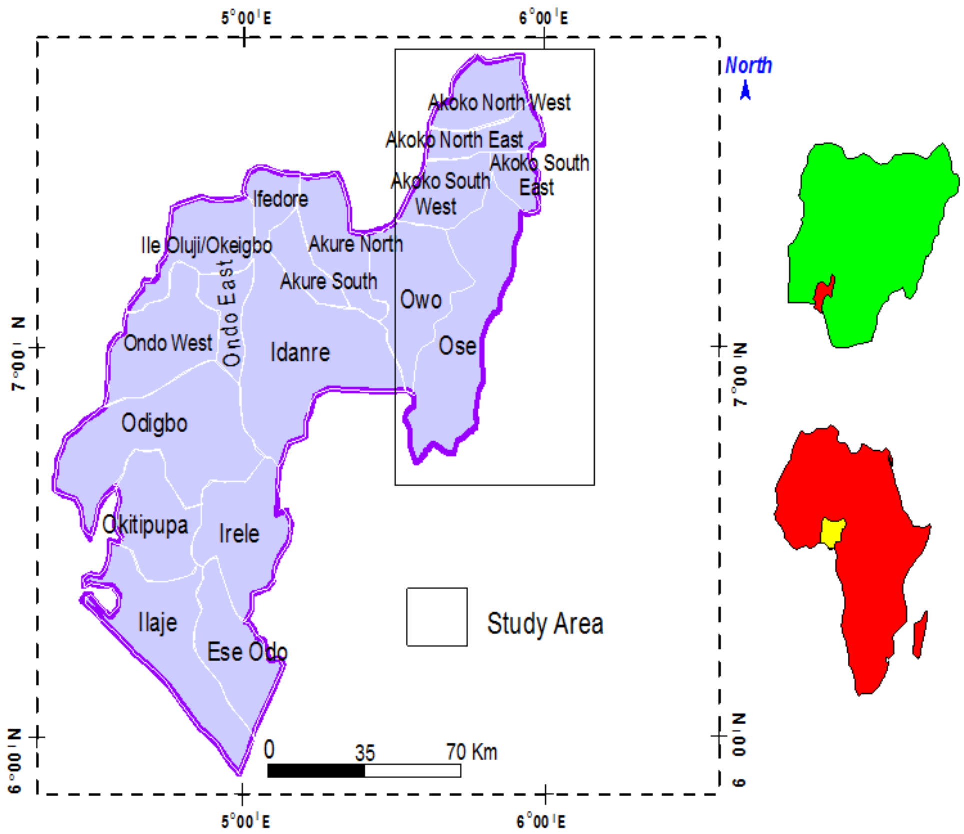

Figure-1. Location map of the study area.
Source: Ministry of works and housing, Ondo State, Nigeria.

The geology of study area falls within the southwestern basement complex Figure 2 and consists of migmatite, granites, granodiorite, granite gneiss, fine grained quartzite, charnockite, pegmatite and quartzo-feldspathic veins, schist, and quartz schist. These rock types dominate Owo and Akoko areas, notably along Owo – Oba Akoko, Iwaro – Akungba, Akungba – Supare, Ikare, Epinmi, Sosan, Oke Agbe, and Ido Ani. The migmatite complex which is the most widespread basement rock in the area is mainly medium grained gneiss. They are strongly foliated rocks frequently occurring as outcrops. On the surface of these outcrops, severely contorted, alternating bands of dark and light coloured minerals can be seen. These bands of light coloured minerals are essentially feldspar and quartz, while the dark coloured bands contain abundant biotite. A small proportion of the area especially to the northeast, overlies the coarse grained granites and gneisses, which are poor in ferromagnesian minerals. These rocks are covered by regoliths with thickness variation across the town. Sand, clayshale, limestone, grift, sandstone, shale, coal, sandstone, and mudstone dominated the southern parts. The sedimentary rocks/deposit is mainly of the post Cretaceous sediments and the Cretaceous Abeokuta Formation.

4. Material and Methods

In total, eight rock samples were collected from different lithological units in the study area which include porphyritic Granite, fine grained Granite, Migmatite, Granite gneiss, Quartz schist, Granodiorite, Charnockite, and Quartzite Figure 2 and labelled as S1 – S8. The sites where the samples were taken are shown in Figure 3. Their geotechnical properties which comprises moisture content determination, Aggregate impact value (AIV), Aggregate crushed value (ACV), Point load strength test, specific gravity, Water absorption test, Unconfined compression test, and direct shear strength test. The values of the presented rock properties were predominantly determined as an arithmetic average of two to five rock specimen tests. All laboratory tests were carried out in accordance with ASTM D– 2216 [30] and ISRM [31] for physical properties such as density, porosity, void ratio, moisture content and water absorption of the samples. The aggregate impact value (AIV) and aggregate crushed value (ACV) were prepared using BS 812: Part 110-112 British Standard Institution 1377 [32]. ISRM [31] IS: 2386 – part -3 for specific gravity determination for coarse aggregate.

Porosity was measured by dividing the amount of water filling the pore spaces, deduced from weight of each sample by density of water at room temperature. Void ratio was calculated based on the dry weight of each rock sample by subtracting one from the product of the sample volume and density, divided by the mass of the sample. Density was estimated from the ratio of bulk mass of each sample to its bulk volume. The mass of each specimen was determined after drying to a constant mass at a temperature of 105° C for 24 hours, and allowing it to cool in the desiccator for about 30 minutes. The volume of each sample was measured from its dimension, while water absorption was calculated as percentage by weight of water absorbed in terms of oven-dried weight of each sample. All numerical data obtained from the measured physical properties were subjected to statistical analysis, including regression plots in order to establish the relationship between the measured physical properties.

The unconfined compressive strength, direct shear strength, point load test were determined as outlined in ISRM [33]. For Point Load, the corrected Point Load Strength Index, $I_{S(50)}$ was calculated using Equation 1.

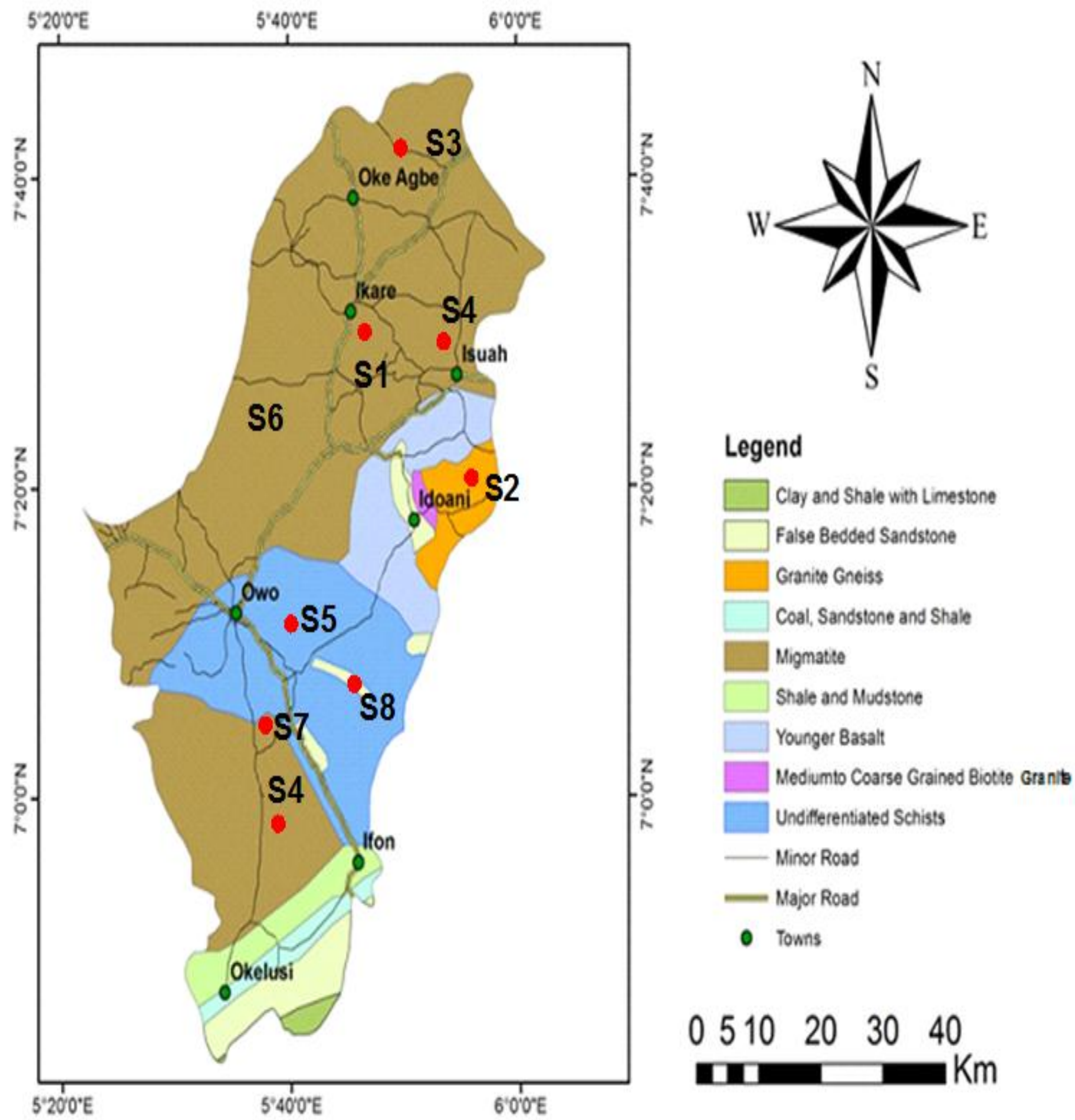

Figure-2. Geological map of the study area showing locations of sample collection.
Source: Nigeria geological survey agency.

$$Is_{50} = (P/D_e^2) \times F \text{ .... } (1)$$

Where:
P = Failure load.
De = Equivalent core diameter.
$D_e^2 = 4A/\pi$ (for axial, block lump test).
A = W × D.
W = Minimal cross sectional width.
D = Minimal cross sectional distance.
F = size correction factor.

$F = (\frac{D_e}{50})^{0.45}$

5. Results and Discussion

The results of the physical properties of the tested rock samples are summarized in Table 1 and 2. The natural moisture content of rock samples varies from 0.15% in Quartzite to 0.43% in Granodiorite. The water absorption potential of the samples ranges between 0.27% (Quartzite) and 0.82% (porphyritic Granite).

Water content is one of the most important factors influencing rock strength. Considerable research has been carried out to investigate rock strength under both dry and water saturated conditions. According to these results, the petrophysical properties of rocks decrease with increasing moisture. Quartzite is a metamorphosed arenaceous rock with granulose texture. Predominantly composed of quartz. Quartzite is usually thought of as thermally metamorphosed rocks but regional metamorphism also produces them. The low moisture content of the quartzite could have as a result of degree of metamorphism which increases the mineral bonding, while the high water obtained in Granodiorite may be attributed to their texture.

The specific gravity of the samples is between 2.65 (Granite) and 2.73 (Granodiorite/Charnockite). The relatively high values obtained for Granodiorite and Charnockite could attributed to their mineral composition, as they tend to contain less quartz but high ferromagnesian minerals which denser and heavier in weight. The values of specific gravity obtained correlated well with range of values for crystalline rocks as reported in Anon [34] and Blyths and Freitas [35].

Figure-3. Various sites where representative samples of the rock units are collected.

Source: Fieldwork, 2017.

The water absorption of the rock samples varies from 0.27 for Quartzite to 0.82 for porphyritic Granite. However the values obtained for granite (approx. 0.5) and Quartzite (approx. 0.3) are very close to those reported in Bell [12] for roadstone properties of some common aggregate in Table 3.

The Dry Unit Weight recorded for the rock units ranges from 26.59 (Quartzite) to 27.04 KN/m^3 (Quartz Schist), while porosity ranges between 0.18 (Quartzite) – 0.46 (porphyritic Granite). According to Anon [34] in Table 4, the rock samples can be regarded as high to very high rocks, since their dry unit weight is greater than 25KN/m^3 (25 Mg m^{-3}). This is consistent with the determined density of metamorphic rocks [5]. The rock units are characterized by low porosity as their values are less than 1. This implies that they are compact and impervious in their natural states. Rock porosity depends on not only the density of the solid matrix material, but also the density of pore fluids as well as saturation.

The aggregate impact value (AIV) gives a relative measure of the resistance of the aggregate to sudden shock or impact. The particular purpose which an aggregate is meant to serve requires the aggregate to have a particular strength which is usually stated in the specification Table 5. This test provides a method for measuring this strength. The values of AIV ranges from 11.2 (Quartzite/Granite Gneiss) to 17.3 (Charnockite). Gneiss has a rough banding or foliation, in which pale coloured bands of quartz and feldspar lie parallel with bands or streaks of mafic minerals Figure 3; the mafic minerals are mainly biotite, hornblende, or in some cases pyroxene. Biotite is often accompanied by muscovite, and garnets are common accessory minerals. A gneiss breaks less readily than a schist and commonly splits across the foliation; it is often coarser in texture than most schists, though some gneisses are relatively fine-grained [35]. Therefore based on this characteristics of gneiss, this might be responsible for low AIV recorded relative to other rock samples. From Table 5, the rock units can categorized as strong aggregate in terms of quality for road pavement. These values of AIV of the rock samples correlate well with some rock units of the same lithology (granite and quartzite) reported by Bell [12]. The aggregate crushing value provides a relative measure of resistance to crushing under a gradually applied compressive load. Aggregate used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, the stability of the pavement structure is likely to be adversely affected. To achieve a high quality of pavement, aggregate possessing low aggregate crushing value should be preferred. The ACV recorded a range of 18.4 (Quartzite) – 25.2 (Charnockite). The aggregate crushing value for road material; cement concrete pavement should not exceed 30%, while ACV for wearing surfaces should not exceed 45%. Therefore the rock units are very excellent as aggregate for road pavement construction.

(a) ACV Test Machine
(b) AIV Test Machine
(c) Aggregates and Basket in water for Water Absorption test and specific gravity
(d) Separation of Aggregate with 2.2mm Sieve after Crushing
(e) Weight Measuring Scale
(f) Different Sieve Sizes of 2.36mm, 10mm and 14mm

Figure-4. Pictures of some equipment and processes undertaken in the course of the laboratory analysis.
Source: Federal University of Technology, Akure, Nigeria.

The point load strength test is used as an index test for strength classification of rock materials. The test method is performed to determine the point load strength index (Is_{50}) of rock specimens. The point load strength index (PLSI) of the samples ranges between 7.40 and 9.87. Charnockite is characterized with relatively high PLSI of the sampled rocks. The Charnockite obtained in the study area are fine to medium-grained, equigranular and massive, sometimes porphyritic. Charnockitic rocks constitute one of the important petrological units within the Precambrian Basement Complex of Nigeria. They are generally characterized by their dark greenish to greenish grey appearance which makes them easily recognizable in hand specimen. They usually contain quartz + plagioclase + alkali feldspar + orthopyroxene + clinopyroxene + hornblende ± biotite ± fayalite. Accessory minerals are usually zircon, apatite, and iron ores [36, 37]. Therefore high value of PLSI observed in the Charnockite could be as a result of its texture and chemical composition. Hence based on Table 6 according to Franklin and Broch [38] the rocks can be categorized as very high strength rock materials with corresponding compressive strength between 50 and 160 MPa, which correlates with the actual values obtained for the sampled rocks i.e. 121 – 185.3MPa. Subsequently using Table 7 and 8, according to Geological Society, International Association of Engineering Geologist and International Society for Rocks Mechanics, they are very strong rock units.

Table-1. Summary of the physical properties of sampled rocks.

Sample no.	Rock unit	MC (%)	AIV	ACV	PLSI (MPa)	SG	WA (%)	UCS (MPa)	ST (MPa)
S1	Porphyritic Granite	0.41	15.2	24.2	7.40	2.65	0.82	121.1	60.5
S2	Granite	0.39	13.1	23.1	8.08	2.69	0.48	143.1	71.6
S3	Migmatite	0.34	14.4	23.1	8.05	2.66	0.57	122.1	61.1
S4	Granite Gneiss	0.38	11.2	19.7	8.82	2.70	0.33	127.5	63.7
S5	Quartz Schist	0.24	12.4	22.2	8.89	2.66	0.66	159.4	79.7
S6	Granodiorite	0.43	12.1	21.1	9.52	2.73	0.44	170.2	85.1
S7	Charnockite	0.34	17.3	25.2	9.87	2.72	0.47	165.9	82.9
S8	Quartzite	0.15	11.2	18.4	8.84	2.65	0.27	185.3	92.6

Note: MC-moisture content, AIV-aggregate impact value, ACV-aggregate crushed value PLSI-point load strength index, WA-water absorption, UCS-unconfined compressive strength, ST-shear strength.

Table-2. Results of the dry unit weight, porosity, and water content of the rock samples.

Sample no.	Rock unit	Dry unit Wt. (KN/m³)	Porosity (%)	Water content (%)
S1	Porphyritic Granite	26.72	0.46	0.16
S2	Granite	26.82	0.37	0.23
S3	Migmatite	26.90	0.37	0.15
S4	Granite Gneiss	26.71	0.38	0.29
S5	Quartz Schist	27.04	0.29	0.12
S6	Granodiorite	27.03	0.30	0.22
S7	Charnockite	26.79	0.31	0.19
S8	Quartzite	26.59	0.18	0.11

Table-3. Some representative values of the roadstone properties of some common aggregates.

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

Source: After Bell [12].

Table-4. Dry density and porosity.

Class	Dry density (Mg m⁻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 2.75	Very high	Less than 1	Very low

Source: After Blyths and Freitas [35].

The shear strength of the samples varies from 60.5 (porphyritic Granite) to 92.6 MPa (Quartzite). Quartzite is derived from the conversion of siliceous rock such as sandstone through the process of metamorphism. The original quartz grains of the sandstone (and siliceous cement if present) are recrystallized as an interlocking mosaic of quartz crystals. Therefore Quartzite in its massive, unweathered state is very strong, in terms of crushing and shear strengths.

Figures 6-11 show regression plots of the physical parameters measured. Porosity, water absorption, specific gravity (SG), and moisture content (MC) are chosen as independent variables, while shear strength (SS), unconfined compressive strength (UCS), AIV, ACV, and PLSI are dependent variables. Figure 4 shows fair positive relationship ($r^2 = 0.4078$) between WA against P. SS and USC have a high positive coefficient of correlation with porosity i.e. $r^2 = 0.8291$; 0.8287 respectively Figure 5 and 6.

Low positive correlation coefficient exists between UCS and MC (0.31); AIV and WA (0.25); AIV and P (0.15); ACV and P (0.32). However ACV shows a fair positive correlation with WA ($r^2 = 0.4815$), while PLSI recorded a good correlation coefficient of 0.5 with specific gravity Figure 11. Therefore from the regression analysis plots, porosity and specific gravity are the major properties that show strong positive correlations with shear strength, unconfined compressive strength, and point load strength index [39].

Table-5. Classification of aggregate based on aggregate impact value.

AIV (%)	Quality of aggregate
<10	Exceptionally strong
10-20	Strong
20-30	Satisfactorily for road surfacing
>35	Weak for road surfacing

Source: Thuro and Plinninger [39].

Table-6. Point load strength classification.

Class	Point load strength index (MPa)	Equivalent uniaxial compressive strength (MPa)
Extremely high strength	Over 10	Over 160
Very high strength	3-10	50-160
High strength	1-3	15-60
Medium strength	0.3-1	5-16
Low strength	0.1-0.3	1.6-5
Very low strength	0.03-0.1	0.5-1.6
Extremely low strength	Less than 0.03	Less than 0.5

Source: After Franklin and Broch [38].

Table-7. Classification of compressive strength of rocks.

Class	Compressive strength (MPa)	Term
1	Over 200	Extremely strong
2	100-200	Very strong
3	50-100	Strong

Source: After Anon [40].

Table-8. Grades of unconfined compressive strength.

Geological Society, Anon [40]		IAEG [34]		ISRM [41]	
Term	Strength (MPa)	Term	Strength (MPa)	Term	Strength (MPa)
Very weak	Less than 1.25	Weak	Under 15	Very low	Under 6
Weak	1.25-5.00	Moderately strong	15-50	Low	6-10
Moderately weak	5.00-12.50	Strong	50-120	Moderate	20-60
Moderately strong	12.50-50	Very strong	120-230	High	60-200
Strong	50-100	Extremely strong	Over 230	Very high	Over 200
Very strong	100-200				
Extremely strong	Over 200				

Source: After Anon [41].

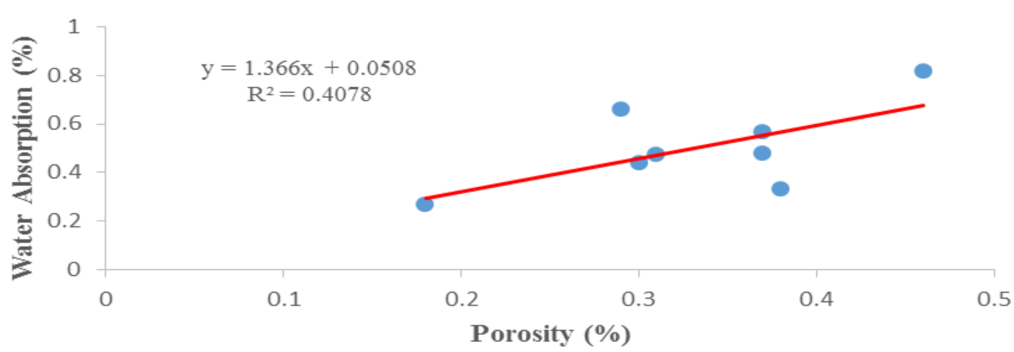

Figure-5. Regression plot of water absorption against porosity.

Source: Data analysis.

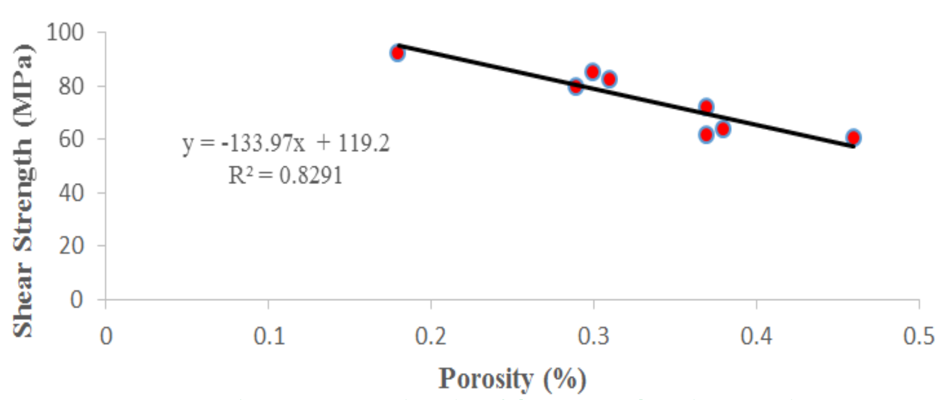

Figure-6. Regression plot of shear strength against porosity.

Source: Data analysis.

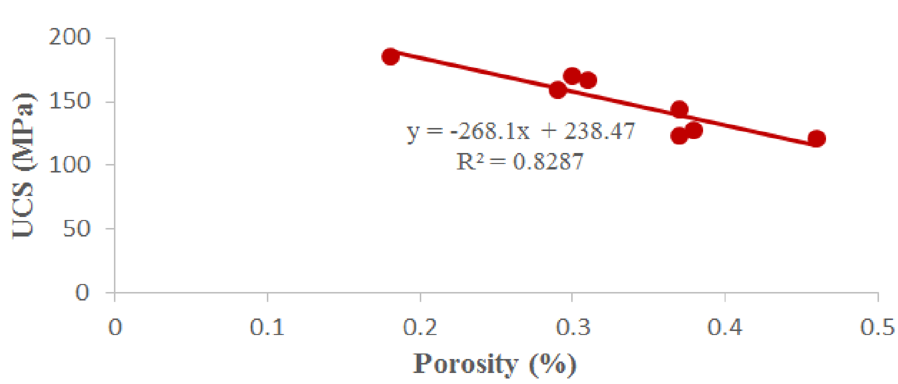

Figure-7. Regression plot of unconfined compressive strength (UCS) against porosity.

Source: Data analysis.

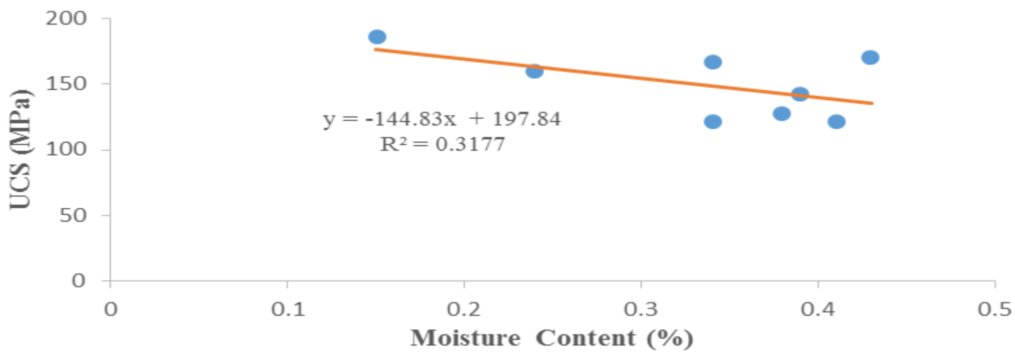

Figure-8. Regression plot of UCS against moisture content.

Source: Data analysis.

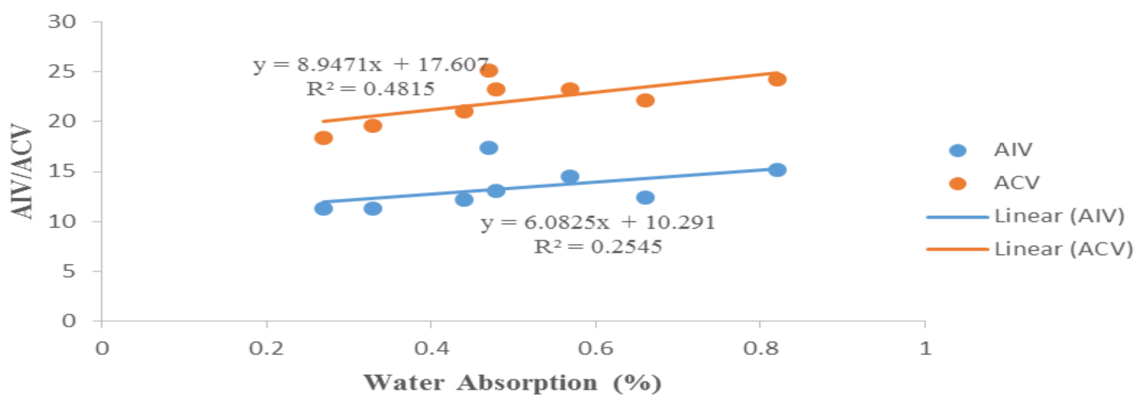

Figure-9. Regression plot of aggregate impact value and aggregate crushing value against water absorption.

Source: Data analysis.

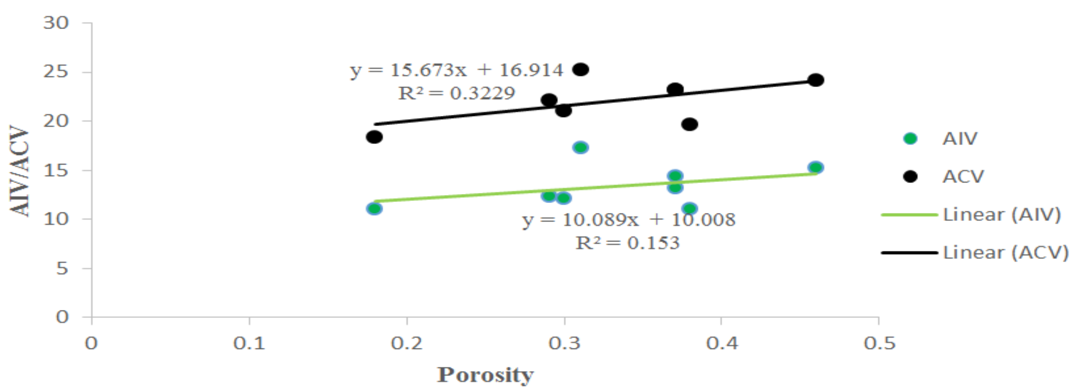

Figure-10. Regression plot of aggregate impact value and aggregate crushing value against porosity.

Source: Data analysis.

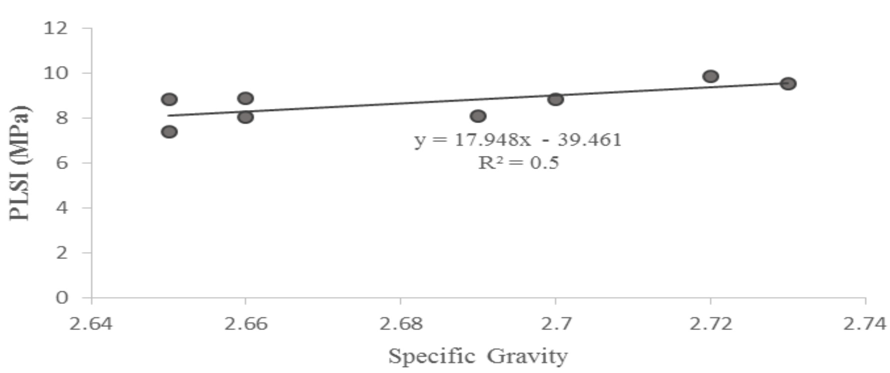

Figure-11. Regression plot of point load strength index and against specific gravity.

Source: Data analysis.

6. Conclusion

The degree at which rocks can be used as building stones, armourstone, aggregate in pavement construction, and concrete depends on physical properties, which is a reflection of compositional features. In order to achieve this parameters such as moisture content, dry density, porosity, specific gravity, aggregate impact value, aggregate crushing value, point load strength index, unconfined compressive strength, and shear strength were determined from eight different lithological rock units. Findings show that the rocks are characterized by low porosity, very high strength on the basis of point load strength index and shear strength. The samples show strong quality as aggregate in pavement construction. However Charnockite seems to have excellent physical properties which could attributed to its texture and mineral composition. It is also observed that porosity and specific gravity are the major parameters that show strong positive correlations with important geotechnical parameters such as shear strength, unconfined compressive strength, and point load strength index.

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