Relationship between Mineralogy and Engineering Properties of Rocks: Implications for Utilization as Aggregates.

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Abstract

With rapid urbanization there is need for civil construction of roads. These roads are constructed using rock aggregates whose engineering properties are often not ascertained. The aim of this paper is to determine the relationship between the mineralogy and the engineering properties of basically three types of rocks namely; porphyroblastic gneiss, pegmatite and granite gneiss. The tests conducted were Los Angeles (LA) test, Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV). The range of values for granitic gneiss for LA, ACV and AIV are 14.9% - 22.6%, 24.0 – 28.3%, 15.9 – 21.4%, for porphyroblastic gneiss; LA, ACV and AIV ranged from; 23.6% - 27.2%, 34.7% - 38.6%, 18.8% - 29.6% respectively. The range for pegmatite for LA, ACV and AIV are; 30.8% - 33.1%, 38.6% - 42.4% and 32.1% - 36.9% respectively. All the tests according to ASTM standard specifications for granitic gneiss and porphyroblastic gneiss satisfy condition for it to be used as road aggregates. Pegmatite of the area falls short of the standard specification to be used for road construction. Granitic gneiss has the highest strength indices of all the tests which can be attributed to its mode of formation and relatively less stress condition. With the results obtained it can be concluded that the rocks satisfactorily meets the standard specification for aggregates used for road construction.

Key words: AIV, ACV, LA Test, Mineralogy, Rock aggregate.

Introduction

Aggregates are supplies gotten from the crushing of rocks. Igneous, metamorphic and sedimentary rock type are formed by different methods and are all connected in the rock cycle. Aggregates are one of the most common materials used in engineering design and construction, and they are bare to a diversity of physical and chemical influences depending on the areas in which they are used. An aggregate should generally be hard, durable, and uniform and clean, as well as highly abrasion-resistant (Teymen 2017).

Sand, gravel and crushed rock aggregates are essential to the artificial environment and represent a large amount of the materials used in the construction industry. Recycle of aggregates has become a more common practice and the replacement of natural aggregates by man-made aggregates made from waste commodities of other industries is a small part of the industry. Quarrying in terms of tonnage is the largest production in the United Kingdom and even in 1985; production was two and a half times that of coal. Utilization of aggregates has more than doubled over forty years from 100 million tonnes in 1959 to between 200 and 300 million tonnes per annum throughout the last decade. Sand and gravel production in 1959 was 67% of the total with crushed rock providing the balance of 33%. By 1998 this situation had changed significantly with crushed rock production increasing substantially to 132 million tonnes (60%) and sand and gravel only to 86 million tonnes (40%). In 1989, growth in demand was strong and a compound growth rate of 3% was forecast leading to expectations of consumption of approximately 400 million tonnes by the year 2000. Approximate figures for aggregate production in other countries during 1995 were, for example, USA 2170, France 365 and Italy 270 million tonnes, respectively. (Verney, 1976)

Despite the significance of geological materials in civil engineering projects, the field of engineering geology has by tradition been concerned more with relations between the engineering structure and its geological environment than with the performance of rock aggregates in the structure itself. This inequality is being documented and attuned in the fields of teaching, practice and research, but an inhibiting factor is the profuse but highly dispersed nature of the literature on aggregate materials (Aitken et al; 1979).

Aggregates from igneous and metamorphic rocks are always highly satisfactory in concrete due to their mode of formation making them denser and highly crystalline unlike the sedimentary rocks that are formed as a result of cementation, compaction and hardening of sediments from other rock types. Although igneous rocks exhibit a very wide array of chemical compositions, their fittingness for aggregate depends also on their mineral constituents, their crystalline framework and texture and the degree of chemical modification and of weathering; these in turn relate to their modes of occurrence (Annon, 1991).

The significance of determining the quality of aggregates becomes clear in light of the fact that aggregates are used 75– 85% by volume in the concrete, and 93–100% by volume in base courses and asphalt mixtures. Aggregates used for these applications must be abrasion resistant to prevent crushing, disintegration and degradation when stockpiled, compacted with rollers, fed through an asphalt plant, placed with a paver and subjected to traffic loadings. It is obvious that aggregates that lack adequate abrasion resistance and toughness will cause performance problems under such usage conditions (Wu et al. 1998).

In developing nations like Nigeria, construction materials are not normally tested to determine the viability or otherwise of such materials (mostly aggregates) in the design and construction of infrastructures. Many quarrying sites were visible in the study area with little or no knowledge of the type of aggregates they are churning out to the public. Failures of institutions saddled with the responsibility of certifying those that are supposed to be in the business and the inability for proper supervision also aids in the collapse of infrastructures within a short time of construction.

The study area falls within Nasarawa State in Karu Local Government area on Latitudes 09° 00’ 00” N - 09° 02’ 51” N and Longitudes 07° 53’ 21” E - 07° 56’ 11” E part of Gitata sheet 187° SE. Angwan Alura and its environs is about 14 kilometres South West of the ancient city of Keffi, Nasarawa state, Nigeria and essentially lies within the Nigerian basement complex. It covers a land mass of about $25km^2$. The only major road in the study area is trending north to south and connects Gidan Kampani, Tudu Uku, Malmara, and Angwan Alura. Other villages within and around the study area are connected by footpaths. The footpaths criss-cross each other particularly in the southwest and southeast as seen (Figure 1).

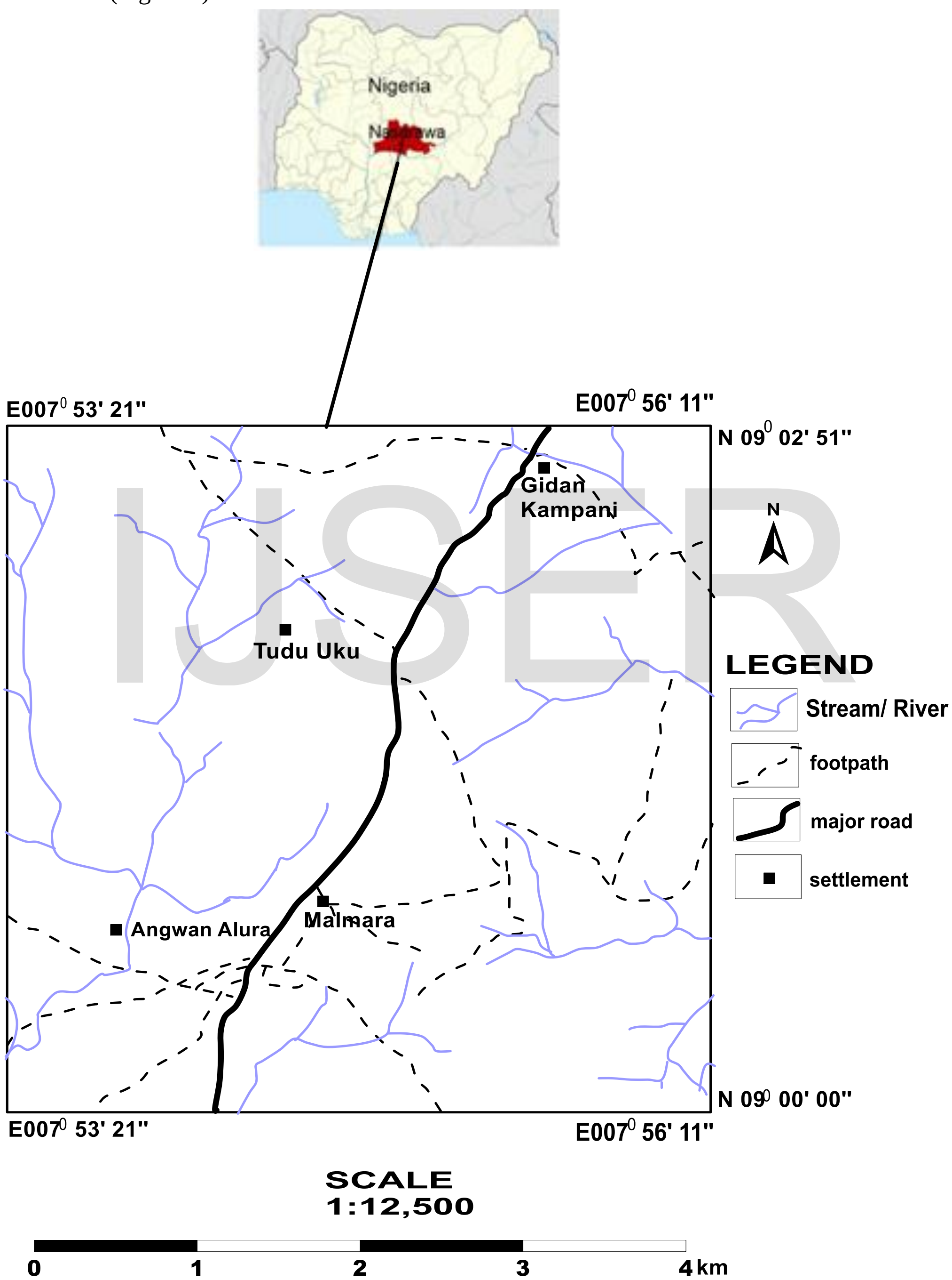

Figure 1: Location, Extent, Accessibility and drainage map of Angwan Alura and Environs.

Methodology

A detailed field mapping was achieved by traversing the study area. This was carried out using a Garmin Global Positioning System (GPS) and compass to navigate the area. The clinometer in the compass was used to measure trend and dip of lithological and structural features on outcrops, Hand lens was used to enlarge mineral grains that were tiny. All observations of minerals at outcrops and measurements at different locations were recorded. Sixteen (16) rock samples were collected at different locations (figure 2) and these samples were labelled as GL1, GL2, GL3 ...GL16 using a water proof marker. Three (3) representative samples were selected for thin sectioning while all were presented for geotechnical studies to determine the strength of each.

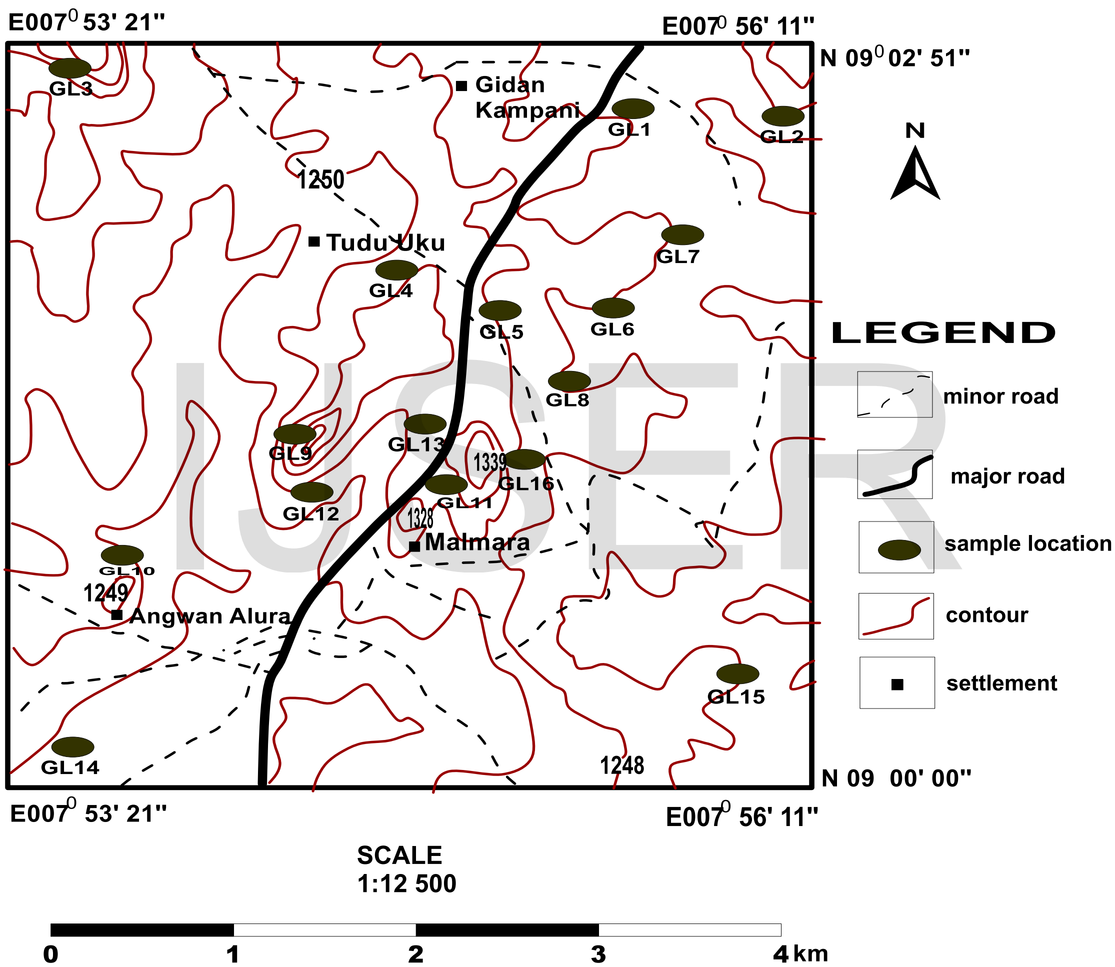

Figure 2. Sample Location Points

The sectioning of the samples was done at the Petrographic laboratory using the Hillquist Thin Section machine (figure 3) of the Department of Geology and Mining, Nasarawa State University, Keffi. The processes of petrographic studies involve cutting the rock into small rectangular pellet of 3mm, mounted on glass slide using resin araldite. The mounted slide was lapped on a glass plate using medium-grain carborundum as abrasive to generate friction between the rock pellet and the glass, in the process reducing the slide thickness to a desirable thickness of 0.3mm. At this thickness, it has been established that rocks behave like a transparent medium allowing the passage of light (Kerr, 1977). Canada balsam was later used to seal the thinned rock using a glass cover lid. Rock slides were studied using a petrological microscope (PLM) NP 107T model to study the various properties of the rock-forming minerals under Plane Polarized Light (PPL) and Cross Polarized Light (XPL).

Figure 3: Cutting Machine

The geotechnical studies carried out on the samples were Aggregate Crushing Value (ACV) and the Aggregate Impact Value (AIV) at the Nigerian Geological Survey Agency Laboratory, Kaduna.

The Aggregate Impact Value (AIV) was carried out by procedure described by the BS 812-110 (1990a). About 350 grams of aggregate that passed through 14mm sieve and retained on 10mm sieve was taken and placed in three layers in the Impact testing Machine and compacted with 25 strokes of the tamping rod. The aggregate was subjected to 15 blows from a standard metal hammer of weight 14 Kg falling from 38cm. The crushed aggregate was removed by holding the cup over a clean tray and hammering on the outside with the rubber mallet and then sieved in the tray on the 2.36 mm test sieve until no further significant amount passed during a further period of 1 min. The masses of the fractions passing and retained on the sieve were Weighed and recorded.

The aggregate impact value (AIV) expressed as a percentage was calculated thus:

$$(AIV) = M2\ M1 \times 100$$

Where

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M 1 is the mass of the test specimen (in g);
M 2 is the mass of the material passing the 2.36 mm test sieve (in g).

Aggregate Crushing Value (ACV) Test: The sample was first sieved using the 14mm sieve and the ones retained on the 10mm BS sieve sizes was collected and oven – dried at a temperature of 100 degrees for five hours. The sample was placed in a cylindrical mould to a depth of 100 mm in 3 layers, with each layer been tamped 25 times with tamping rod. The top was leveled with the plunger by a slight rotation of the plunger while placed on aggregate in the mould. The sample, in the mould with the plunger, was placed in the compression testing machine and compressed at a uniform rate till a force of 400kN was applied such that this force was achieved in 10 minutes. The load was released after this time and the sample was sieved through a 2.36mm sieve. The weight of material passing through the sieve and that retained were determined and recorded. This weight was expressed as a percentage of the original mass to give aggregate crushing value (ACV). This test was performed 3 times for each aggregate specimen and the average calculated and recorded.

RESULTS AND DISCUSSION

Geology of the Area

The study area is part of the Precambrian Basement Complex of North Central Nigeria and consists mainly of three lithologies; porphyroblastic gneiss, granitic gneiss and Pegmatite. The porphyroblastic gneiss occurs as low lying outcrops and covers about 30% of the area. The medium grain granitic gneiss covers about 60% of the exposures of the study area while the pegmatite covers just 10% (figure 4). The porphyroblastic gneiss mostly outcropped at Angwan Alura and some parts of Tudu Uku extending towards the Eastern (Kutu) part of the study area. The granitic gneiss outcropped dominantly in Angwan Alura, Malmara and Gidan- Kampani (Figure 4).

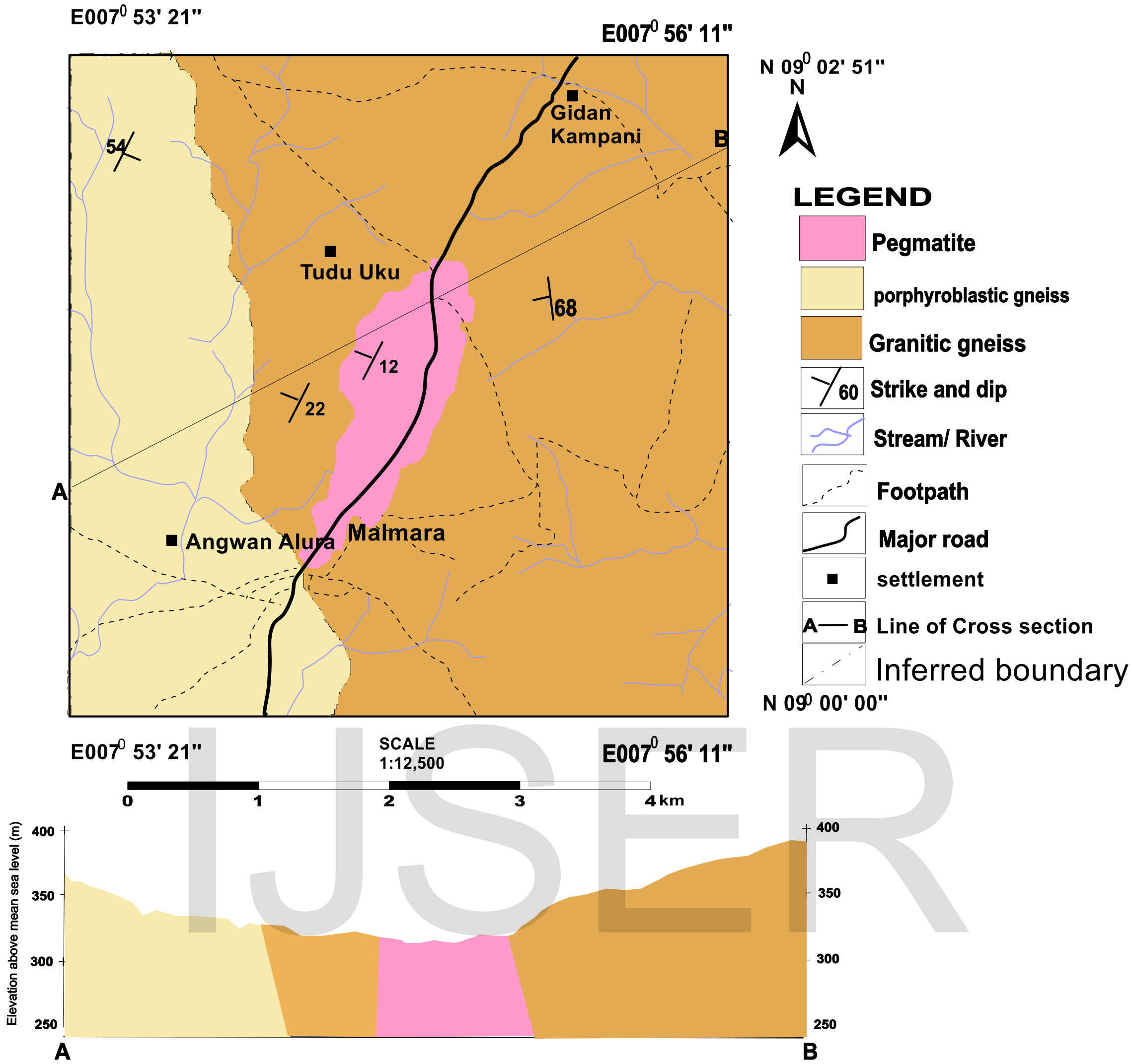

Figure 4: Geological map of the study area

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Relationship between mineralogy and strength of the rocks

Table 1: Photomicrographs of rock types in the area

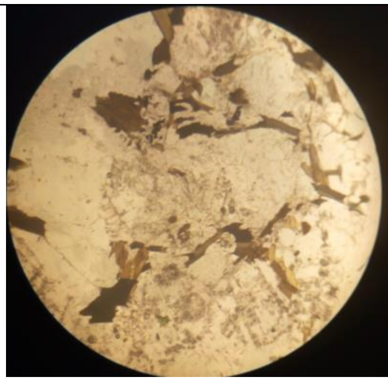
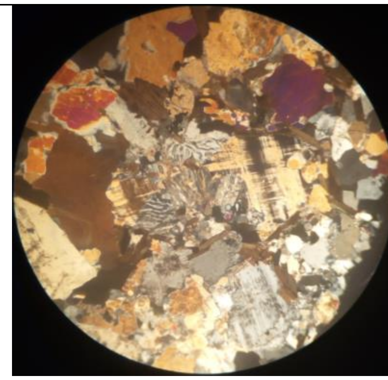
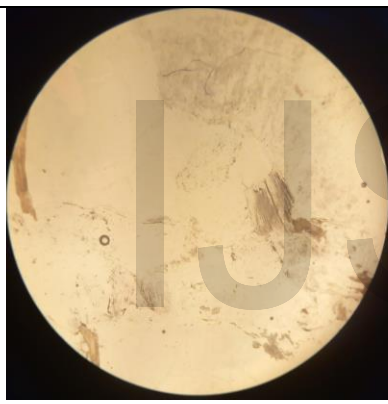
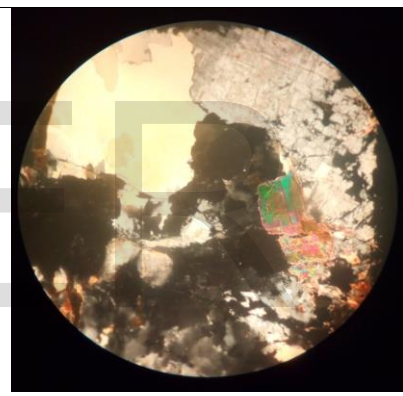
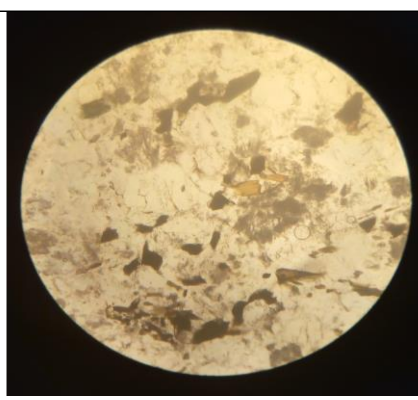
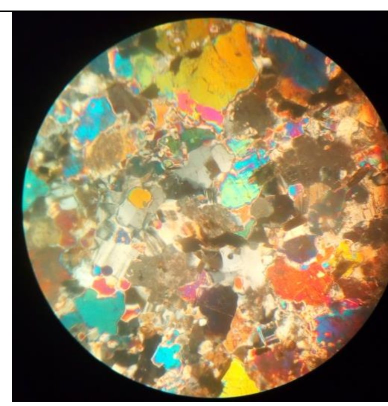
Photomicrograph under plane polarised light	**Photomicrograph under cross polarised light**
 **a**: Porphyroblastic Gneiss	 **b**: Porphyroblastic Gneiss
 **c:** Pegmatite	 **d:** Pegmatite
 **e:** granitic gneiss	 **f:** granitic gneiss

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Table 1 above present petrography of the different rock types in the area. the petrography brings out the different mineral grains, their shape and arrangement in the rock matrix.

Table 2: Average mineral Composition in rocks of the study area.

S/N	Minerals	Modal Composition (%) of Porphyroblastic Gneiss
1	Quartz	50
2	Biotite	30
3	Plagioclase	15
4	Accessory	5
	TOTAL	100
S/N	**Mineral**	**Modal Composition (%) of Pegmatite**
1	Quartz	50
2	Plagioclase	30
3	Orthoclase	10
4	Muscovite	6
5	Accessory	4
	TOTAL	100
S/N	**MINERAL**	**Modal Composition (%) of Granitic Gneiss**
1	Quartz	40
2	Biotite	25
3	Muscovite	20
4	Orthoclase	11
5	Accessory	04
	TOTAL	100

Table 3: Strength Parameters and Rock Types of the Study Area

Rock Id	Rock Name	Rock Type	LA %	ACV %	AIV %
GL1	Granitic Gneiss	Metamorphic	16.2	25.1	15.9
GL2	Granitic Gneiss	Metamorphic	14.9	24.3	17.1
GL3	Porphyroblastic Gneiss	Metamorphic	23.6	34.7	18.8
GL4	Granitic Gneiss	Metamorphic	16.1	28.3	16.7
GL5	Pegmatite	Igneous	32.5	42.1	34.8
GL6	Granitic Gneiss	Metamorphic	19.8	26.5	19.6
GL7	Granitic Gneiss	Metamorphic	22.3	25.1	17.5
GL8	Granitic Gneiss	Metamorphic	21.1	25.7	18.7
GL9	Granitic Gneiss	Metamorphic	21.5	24.0	17.4
GL10	Porphyroblastic Gneiss	Metamorphic	26.8	36.3	29.6
GL11	Pegmatite	Igneous	30.8	39.3	32.1
GL12	Granitic Gneiss	Metamorphic	20.6	26.9	19.3
GL13	Pegmatite	Igneous	33.1	42.4	33.8
GL14	Porphyroblastic Gneiss	Metamorphic	27.2	38.6	28.9
GL15	Granitic Gneiss	Metamorphic	22.6	26.1	21.4
GL16	Pegmatite	Igneous	31.7	38.6	39.9
Standard Specification for Aggregates			<30	<35	<30

Porphyroblastic Gneiss

Porphyroblastic gneiss occurs as coarse-gained foliated rock with porphyroblasts of quartz with low lying outcrop in the south while the exposures in the northwestern part are hilly with dip angle averaging 54ºNW. Typical of gneissic rocks, It has a foliated texture of light and dark bands; the light bands are quartz and feldspars, while the dark bands are biotite, amphibole and magnetite which occur as accessory.The parallel layers produce a banded structure which strictly speaking, act as a plane of weakness in the rock mass thereby reducing the strength of the rock.

The relatively high strength of porphyroblastic gneiss as summarized in table 3 can be attributed to the high content of silica (50%), biotite (30%) and plagioclase (25%). Althogh the banding can be a drawback to the strength, the even grained and crystalline nature complimented for relatively high strength.

Pegmatite

Pegmatites are light coloured and occur as coarse grained, low lying outcrop and covers about 10% of the study area. (figure 4).

The comparatively low strength of this rock as seen in table 3 can be linked to the mineralogical composition as shown on table 2. The presence of silica, orthoclase and plagioclase feldspars would have added to the strength of the rock however, the presence of muscovite and the porphyritic texture of the rock is a major setback to the strength of the rock especially if they are to be used as aggregates.

Figure 6 : Pegmatite sample in the Study Area

Granitic Gneiss

Granitic Gneiss were identified in the field as low lying exposure covering about 60% of the study area. The rock is medium to coarse grained with minerals including quartz, feldspar, biotite and plagioclase (figure 7).

Figure 7: Granitic Gneiss outcrop in Agwan Alura.

Thin section reveals minerals such as quartz, muscovite, orthoclase and biotite as constituents of the rock.

The rock types in the area (granitic gneiss and porphyroblastic gneiss) are metamorphic rocks and have similar mineralogy except for their grain sizes. With reference to table 3 above, the relatively high strength of granitic gneiss and the porphyroblastic gneiss compared to pegmatite which is igneous in origin can be attributed to the stress regime they have underwent and the mineral banding or foliation observed in which often serve as plane of weakness.

The extremely high strength of the rock is the fact that the rock is more compact than all the other rock types. The mineralogy also is an important factor even though with little or no variation from the porphyroblastic gneiss.

Conclusion

It can be concluded from the analyses carried out that although there is a strong relationship between the engineering properties of rocks and the mineralogical composition, the history of the rock is equally important as rocks with similar mineralogy but different geologic history may have different strength. The granite gneiss showed generally satisfactory high strength values for the entire test, thereby making it the most suitable in terms of engineering design and construction that desire the use of high quality aggregate like runways and high-tech engineering constructions. The porphyroblastic gneiss even though with it relatively high strength, cannot be used in the engineering constructions that requires high quality and pegmatite as far as their utilization as road aggregate are concerned

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